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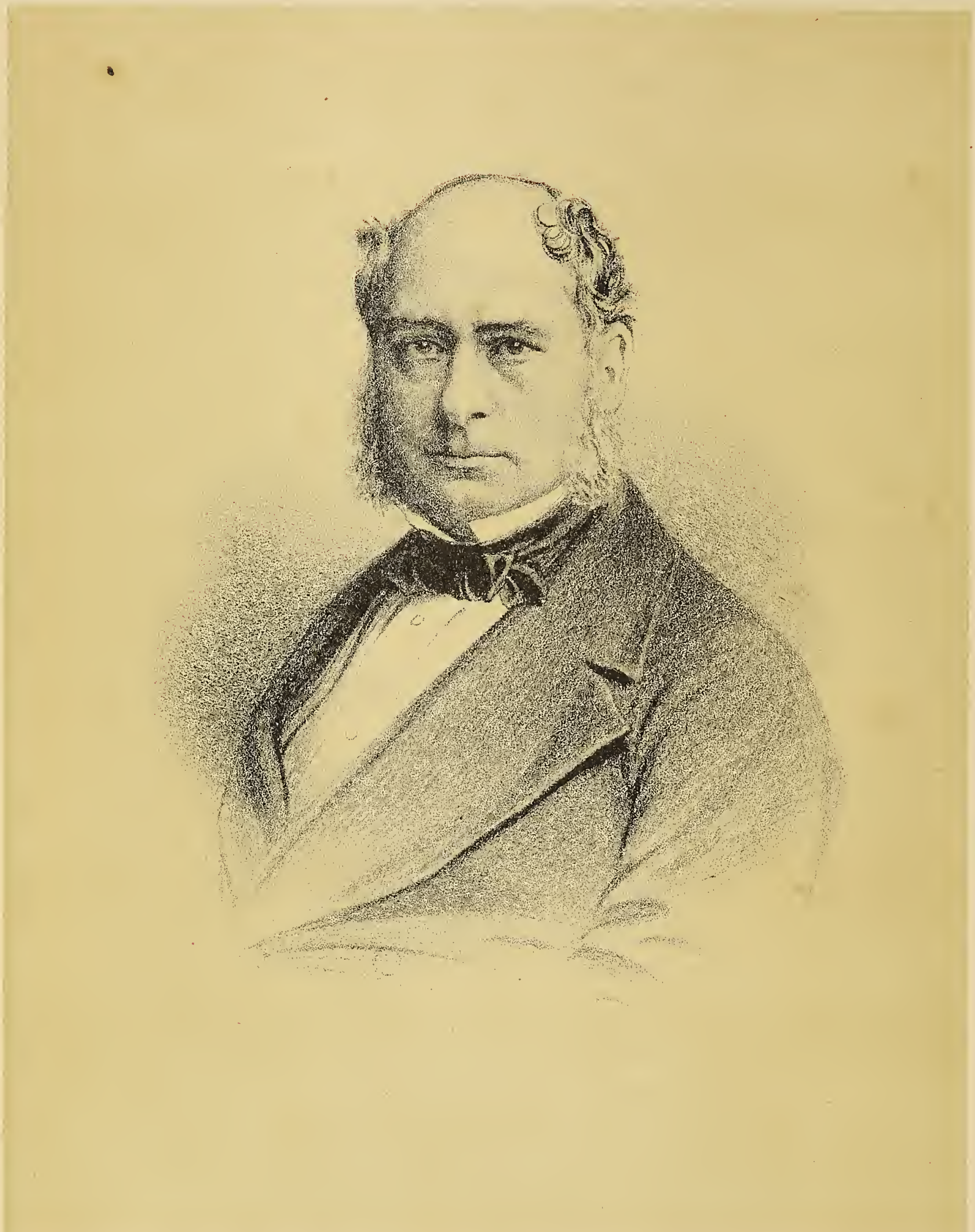

Sir Henry Bessemer

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THE

INDUSTRIES OF THE WORLD

A COMPLETE COURSE OF

TECHNICAL EDUCATION

FOR THE

MANUFACTURER, OPERATIVE,

AND

ALL PERSONS ENGAGED OR INTERESTED IN TRADE AND COMMERCE.

EDITED BY JAMES WYLDE,

EDITOR OF THE "CIRCLE OF THE SCIENCES," AUTHOR OF THE "BOOK OF TRADES," "MAGIC OF SCIENCE," "USEFUL PLANTS," "ORES, METALS, AND THEIR USES," ETC.

ILLUSTRATED WITH ENGRAVINGS, DIAGRAMS, AND PORTRAITS.

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VOLUME I.

THE LONDON PRINTING AND PUBLISHING COMPANY, LIMITED,
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A PRACTICAL BOOK FOR PRACTICAL MEN.

THE

INDUSTRIES OF THE WORLD

BEING A COMPLETE COURSE OF

TECHNICAL EDUCATION

FOR THE

MANUFACTURER, OPERATIVE,

AND ALL PERSONS ENGAGED OR INTERESTED IN ANY OF THE FOLLOWING SUBJECTS:

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TYPEFOUNDING AND SETTING
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WATER GILDING
WHEELWRIGHT
WHITE-LEAD MAKING
WINE-MAKING
WOOL AND ITS INDUSTRIES
&c., &c.

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LIST OF PLATES.

VOL. I.

THE

INDUSTRIES OF THE WORLD.

RISE AND PROGRESS

OF THE

SCIENCES, ARTS, AND MANUFACTURES.

It has been well said that Man *wants* but little; but what he *needs*, in a civilised state, it would be difficult to define or limit. The Esquimaux in his snow hut, surrounded by fields and mountains of unmelted ice, and the Mid-African savage, under the burning heat of a tropical sun, suit their wants in regard to food, clothing, &c., according to the circumstances under which they exist, and it is highly probable that, taking the average of their entire existence, they literally enjoy themselves in their rude simplicity. They toil not, nor do they spin; they take no thought for to-morrow; they are unburdened with either the pleasures or pains of intellectual qualities. If illness, accident, or trouble overtake them, they resort to their gods and charms, or their wise men, and all these failing, they exhibit, often, a stoical firmness, which, amounting to a belief in fatality, leaves them simply to submit to fate—what will be will be, is their last resource.

What a contrast to civilised life in which the Sciences, Arts, and Manufactures have introduced so many elements of pleasure, but, at the same time, so many causes of discomfort! Yet it must be remembered that it is civilisation which has been the promoter of the Sciences, and their technological applications. Intellect has created and supplied the needs which its cultivation has imposed on us. A refinement of taste has removed us from the barbarous practice of painting our bodies, to the more refined one of dyeing and painting our clothes. The rough and ready method of cooking a cake in the sand of the desert has been replaced by the most elaborate arrangements for our culinary purposes. Science has not only provided for our wants while in a state of health, but ministers to our necessities in sickness. In fine, we may remark that the great distinction between savage and civilised life consists in the fact that the existence of the former is governed purely by the *animal*, while in the latter *intellect* is the governing principle.

We purpose here, as introductory to the general objects of this work, to give some details of what Science, the Arts, and Manufactures have done in removing us from the state of barbarism to which we have just alluded.

First, as regards *Science*.

It may be well, if we pause, at the beginning of our duties, to consider briefly a few of the pleasures and benefits that Science perpetually affords us. Until recent years, little popular taste existed for its pursuit. A few favoured and earnest thinkers devoted life-long energies to unravelling the mysteries with which earth, air, and heaven abound; but their researches were generally thought to be of little interest to others, and, too frequently, were neglected until some astonishing application of Nature's laws became so universal as to demand, from all classes, a tribute of praise or thanks to its originators.

Since the commencement of the present century, such a reproach on human intellect and discernment has been gradually wiped away. Now, science has become indeed a household word, and a knowledge of its principles is as needful as any other can be. Its teachings reform the sanitary errors of our social life, and lead to what may be considered a maximum of health and happiness. Rightly applied it multiplies the fruitfulness of our land, converting what were once wastes into smiling fields of corn. It draws, from the bowels of the earth, riches

more fabulous in value than the wildest dream of ancient Eastern imagination could suggest. It keeps thousands, nay, millions, in happy and prosperous livelihood—finding employment for those who, in its absence, must have suffered a painful and wretched existence. It bridges over rivers, seas, and oceans; guiding in the storm and tempest, when no guide but itself exists. It gives us the power to converse with persons who can hear our voice conveyed in its natural tones, scores of miles away. We can, by the electric telegraph, express our wishes, or send our news through thousands of miles in a few seconds. It pierces the arcana of the heavens, and tells us of space and motions almost beyond our finite intelligence. Nay, more—it opens out the infinite to the finite, and lifts the veil which had so long hid the created from the Creator and His wonderful works.

But many of our readers, while admitting the truth of all we urge, yet feel no disposition to enter into a study that, viewed in the general light in which we have feebly placed it, seems pleasing; but, in its careful pursuit, is apparently rugged, difficult, and even repulsive. In this respect they are utterly at variance with those who have spent, or are spending, a life in earnest study of nature. In many parts of the northern portions of this kingdom, but more especially in Switzerland, the traveller, after climbing a rugged mountain, sees, in the expanse before him, nothing but bare mountain-tops, devoid of everything attractive, save their uncouth grandeur. A few hours' journey, however, brings him into lovely valleys, teeming with the richest produce. So those who, ignorant of science, would try to comprehend at once its beauties, find its early steps rugged and hard to tread; while he who patiently overcomes these early elementary, or first teachings, gradually, but surely, acquires a taste for its pursuit; this taste ripening into a fascination, the power of which overcomes all other, and affords, next to the study of the highest of all truths, the deepest and most lasting pleasure, contemplative or reflective, that a man can enjoy.

On this subject we conclude by quoting the remarks of a master-mind—Lord Brougham. He says:—"There is something positively agreeable to all men—to all, at least, whose nature is not most grovelling and base—in gaining knowledge for its own sake. When you see anything for the first time, you at once derive some gratification from the sight being new; your attention is awakened, and you desire to know more about it. If it be a piece of workmanship, as an instrument, or machine of any kind, you wish to know how it is made; how it works; and of what use it is. If it be an animal, you desire to know where it comes from; how it lives; what are its dispositions; and, generally, its nature and habits. You feel this desire, too, without at all considering that the machine or the animal may ever be of the least use to yourself practically; for, in all probability, you may never see them again. But you have a curiosity to learn all about them, because they are new and unknown. You accordingly make inquiries; you feel a gratification in getting answers to your questions; that is, in receiving information, and in knowing more—in being better informed than you were before. If you happen again to see the same instrument or animal, you find it agreeable to recollect having seen it formerly, and to think that you know something about it. If you see another instrument or animal, in some respects like, but differing in other particulars, you find it pleasing to compare them together, and to note in what they agree, and in what they differ. Now all this kind of gratification is of a pure and disinterested nature, and has no reference to any of the common purposes of life; yet it is a pleasure, an enjoyment. You are nothing the richer for it; you do not gratify your palate, or any other bodily appetite, and yet it is so pleasing that you would give something out of your pocket to obtain it, and would forego some bodily enjoyment for its sake. The pleasure derived from Science is exactly of the like nature; or, rather, it is the very same. For what has just been spoken of is, in fact, Science, which, in its most comprehensive sense, only means *Knowledge*, and, in its ordinary sense, means *Knowledge reduced to a system;* that is, arranged in a regular order, so as to be conveniently taught, easily remembered, and readily applied."

In such terse and effective terms may the study of Science be recommended to all our readers; but the object of our work only commences here. First expounding the Science of each subject in its unapplied form, we afterwards proceed to point out its economical value, or, in other words, show how Science may be, has been, and ever will be, of money-value to individuals, to communities, and to nations. It will be shown how the adoption of science, in various industrial processes, has caused us to outstrip, in half a century, our ancestors, whose labours, not a fraction so successful, may be counted by centuries of snail-like progress. It is

useless, as human nature is constituted, to appeal simply to the highest sentiments alone. There are a few, but few indeed, who live disinterested lives, not for themselves, but for others. But self-interest is certainly the nearest approximation, at least morally, to perpetual motion that has yet been known as a principle of action; and however high men may value themselves in the abstract, their practical and social valuation generally descends to the level of the personal benefit they may derive or afford from a pursuit.

This motive for action, however, although apparently selfish, has been productive of the greatest advantage in every sphere of life. It is the desire "to get on in the world," exercised, fostered, and gratified, that leads to the erection of our immense factories, warehouses, docks, and other mercantile appliances; and so far as we are concerned, it will be our object to show, not only how Science has been employed for such ends, but also to enter into minute detail of each of its applications for that purpose. We shall, therefore, be *practical;* and whilst delighting personally in the beauties of Science as a pursuit for the mind, it will be our duty to explain, not only how its benefits have been realised, but to assist any and all of our readers to that desirable end. There is in Science a mine of wealth, both for the mental and pecuniary profit of all; and we shall leave others to make their own choice in respect to these two objects, which its study so bountifully lays open to us.

Next, in respect to the *Arts.*

We must here state that this work has nothing to do with what are called the *Fine Arts*, but only with those generally known as the *Useful Arts.* Art is the practical application of knowledge to the production of all things that can administer to the uses of man—to the lowest necessities of the body, as well as to the highest qualifications of the mind. The word *Art*, then, is very comprehensive. He that makes a shoe, and he that paints a picture, by which his powers of taste and intellect are conveyed to others, is equally an artist in the strict sense of the term The skilful practiser of every science is, to use the expressive term of Lord Bacon, an *Artsman.* Our modern phrases are *Artificer* and *Artisan.* To take only the larger groups of the productions of Art, it would contain, in the leading division alone, which we are accustomed to call the Useful Arts, examples of all the various products and processes that have relation to our daily sustenance, their sources and the modes of cultivation, their preparation into a saleable form, and the arrangements for bringing them within the reach of the consumers. Again, we have to deal under this definition with the materials which we employ for clothing, the rearing and tending of animals, or the vegetables which supply them with food, and the subsequent transformation of them into cloth and leather; the ingenious and often complicated arrangements whereby our secondary wants of fire, artificial illumination, and water are supplied; the houses we inhabit, from the labourer's cottage to the palace of the king, and all the multifarious processes involved not only in rendering these homes habitable, but also healthy, and in many cases, elegant for the occupier's use. The Useful Arts further embrace the means which are afforded us of travelling, whether by roads, railways, canals, or other means of transit; the method of obtaining and utilising the riches which the mineral world affords us, and the means of reducing the metals into forms, by mechanical appliances, so as to produce the almost endless kinds of engines and other apparata so familiar in our daily life. Under the same category are embraced Pottery, Glass Manufacture, Photography, the production of Chemicals used in almost every branch of Manufactures, and other analogous products. Philosophical Instruments, Clocks, Watches, Chronometers, Printing, Engraving, &c., are also included under the generic term of *Useful* Arts.

Our great Exhibitions since, and of course inclusive of that of 1851, have been illustrations of what Useful Arts, in connection with Manufactures, can do for our necessities, convenience, comforts, and luxuries. It will thus be seen that while Science is at the basis of our improvements, Art is its fashioner, and leads to that great branch of human labour called Manufactures.

Last in the order, therefore, comes the subject of *Manufactures.*

Under this heading, of course, most of our future pages are included; but it may be desirable briefly to notice how Science and Art have led toward the development, improvement, and extension of mechanical industry in its various branches. From the remarks already made it is evident that the most extensive knowledge of Science does not necessarily make a man either an artist, an artificer, an artisan, or a manufacturer. A man may be an able astronomer, and yet perfectly incapable of reducing to practice his knowledge to fit him to become the commander

of a vessel, a quality necessarily dependent on a knowledge of the art of navigation. Again, a man may hold a foremost position as a manufacturer, while he has apparently but the slightest knowledge of the principles of Science. It is owing to the advance of the knowledge of Science and Art that during the last half century our manufactures have made such astonishing progress. Perhaps nothing will better illustrate our position than by referring to arts which have existed from the earliest ages of man—those of Agriculture and Dyeing. Each of these has been successfully followed for thousands of years without the slightest knowledge of Science on the part of those pursuing them. But within the last half century, during which Science has unfolded the laws on which man had previously worked in ignorance, the progress of those arts has been astonishing, and the result has been of enormous benefit to the human race in increasing production, and reducing cost, and thus of laying open for the use of many, comforts and luxuries to which our ancestors were entire strangers.

In tracing the rise and progress of Manufactures, we must, of course, trench considerably on the subjects dealt with in the following pages. But one advantage will arise—it is that of putting in possession of the reader a general glance of the principles and practice that will be hereafter considered in minute detail.

Among the most important of all the Useful Arts in which man engages, are those of Mining, Metallurgical and Machine, or Engine Industries. The earliest history of our race relates to manufactures in metals. That they have been the object of attention in all ages, we have abundant evidences from the writings of the sacred and profane historians. We read in Genesis iv., v. 22, that Tubal-cain was "an instructor of every artificer in brass and iron." Homer in his *Illiad* constantly refers to the manufacture of the shields, armour, &c., of his heroes, and the shield of Achilles, and the works of the god Vulcan still further illustrate how early man discovered the ore and reduced it to the metallic form, either for domestic or warlike purposes. In our own country we have illustrations constantly found of the bronze and iron ages in remains picked up. Sometimes an old relic is dug up from buried ruins; sometimes a tomb is opened, and is found to contain urns or other articles in metals; at other

Fig. 1.—Specimens of Roman Manufactures in Metal, found in Britain.

times a bas relief, or a rude painting, or an illuminated manuscript gives us some idea of the Metallurgic Art of our ancestors. The preceding engraving illustrates some specimens of Roman manufactures in metal that have been found in our country (Fig. 1.)

Those of our readers who have access to the collection of the British Museum, will find a large number of objects illustrating the early results of metal-working. In this the ancients seem to have made great progress. Their designs were artistic, and their workmanship excellent, and as an illustration of this the following engraving, representing in three views a bronze Roman bowl, found in Wiltshire, is given. (Fig. 2.)

Fig. 2.—Three representations of a Roman Bronze Bowl, found in Wiltshire.

The puzzle, however, to modern scientific men is not how the ancients artistically fashioned the metals, but how they were able to reduce them from their ores. Gold, of course, is always found in a native state, and requires no chemical processes for its conversion into a malleable or ductile metal, except the ordinary process of melting, &c. Silver, to a certain extent, may be considered as falling under the same category. But taking the chief metals on which our manufacturing industry and that of the ancients depended—namely, iron, copper, tin, and lead, very different circumstances arise. These metals are, for all practical purposes, never obtained in a pure state. They are generally found combined with oxygen as oxides, with sulphur as sulphides, and with carbonic acid as carbonates, and in these forms they require a large amount of fuel, &c., for their reduction to the metallic state, the use of fluxes, and an enormous heat in the case of iron and copper. At the present day all these operations are carried on by the use of coal, or of coke produced from coal. In our country, and on the continent, as also in the United States, coal is sufficiently abundant for the purpose. But in ancient times there was no other fuel known for metallurgical processes than wood, converted by slow burning into charcoal. With this it is astonishing how the ores of iron, &c., could have been reduced into the metallic state. Another matter of importance to notice is that it is a happy thing for our

country that iron ores occur not only in the vicinity of, but are actually associated with the coal necessary to separate the metal from the impurities of the ore ; we have also, in many cases, the concomitant presence of limestone, which is used as a flux, or means of more readily reducing the ores, and parting from the metal its impurities in such a form as that they can be readily removed. At the present day, in Sweden, and many other countries where iron mines exist, the ore is reduced by charcoal ; but no space on the surface of our island could grow sufficient wood to supply the demands for fuel for smelting iron ores. Fortunate, therefore, is it that we have such an abundant supply of coal to depend on, which is now raised from our mines to the extent of about 150,000,000 tons annually, at prices varying in ordinary times from four shillings to eight shillings per ton at the mouth of the pit, while the iron ore averages from ten to fourteen shillings per ton. It is to this that Great Britain owes her supremacy over the rest of the world in regard to metal manufactures, but especially in respect to those relating to iron.

It would appear that so far as our country is concerned, tin was the metal first known and worked. It formed an article of commerce in very early times, especially with the Phœnicians, long before the invasion of Britain by the Romans. Tin works appear to have been carried on here before the use of iron was known. Many tools of oak, obviously used in mining are occasionally found in old works, which tradition among the miners ascribes to the Saxons and Danes, but were likely the rude instruments employed by the ancient Britons.

At this period the art of Mining must have been in the crudest state. There were no means of raising either the ores, or the water in the mines, except by manual labour. Consequently the work was chiefly confined to getting the ores which were nearest the surface. It is, indeed, probable that nearly all the tin procured in former ages in our country, was by means of stream works, in bottom or low ground, where fragments of the ore, washed from lodes in the neighbouring hills subsided and were separated from the earth in a granular form by washing —hence the modern term of "Stream-tin."

In respect to mining for copper in Cornwall, it appears that our early ancestors paid no attention to it. Even in the tin mines, which, as they deepened produced copper, as is often the case, its ore was thrown on one side as useless, and at a recent date these heaps of unsmelted copper have, by modern science, been made a subject of great commercial profit.

The history of iron mining in England is involved in much obscurity. In the *Philosophical Transactions* of the Royal Society for 1678, a description is given of some iron-works in the Forest of Dean. For the smelting of the ore, it is stated that the first workers made use of no other bellows but such as were worked by the strength of men, by reason of which their fires were much less intense than the furnace they now employ. The improved mode adopted in 1678 in thus described in the paper referred to above :—"This (the furnace) is furnished with two huge pair of bellows, whose noses (nozzles as we now say) meet at a little hole near the bottom ; these are compressed together by certain buttons, placed on the axis of a very large wheel, which is turned about by water in the manner of an overshot wheel ; as soon as these buttons are shot off, the bellows are raised again by the counterpoise of weights, by which they are made to play alternately, the one giving its blast while the other is rising."

What a contrast to the mechanical arrangements of our date ! With us the rude bellows of old have been replaced by the most elaborate contrivances for supplying any amount of air to the smelting furnace, and at any desired pressure. Moved by powerful steam-engines, the air is pumped into large receivers, and thence conveyed to the bottom of the smelting furnace. Into the details of all such contrivances as now used, we shall fully enter in the following chapters. The following engraving (Fig. 3), however, will suffice to enable those of our readers who are unacquainted with the methods of iron-smelting to understand the principle of the process.

If we were to select an iron furnace of the usual construction, and suppose it to be cut down through the middle from top to bottom, we should find it to present the various arrangements shown in Fig. 3. This is a furnace for making "pig" iron, and in which coke is the fuel employed. The height from the bottom at A to the filling-place at B is about eighty feet. The general material of the furnace is brick, lined on the inside at E with a double circle of fire-bricks, having an intervening space filled with sand ; F F, the hearth, is composed of large blocks of stone ; D is the general cavity of the furnace, filled with the burning materials ; and C A is a contraction of the space, to prevent the materials from blocking up the place of exit ;

G G are the nozzles of the blowing engines, by which a blast of air is forced in among the glowing contents of the furnace.

It is needless to add that the present effective and economical methods of smelting have been arrived at by slow degrees, even during the present century, but this will be a question for future discussion.

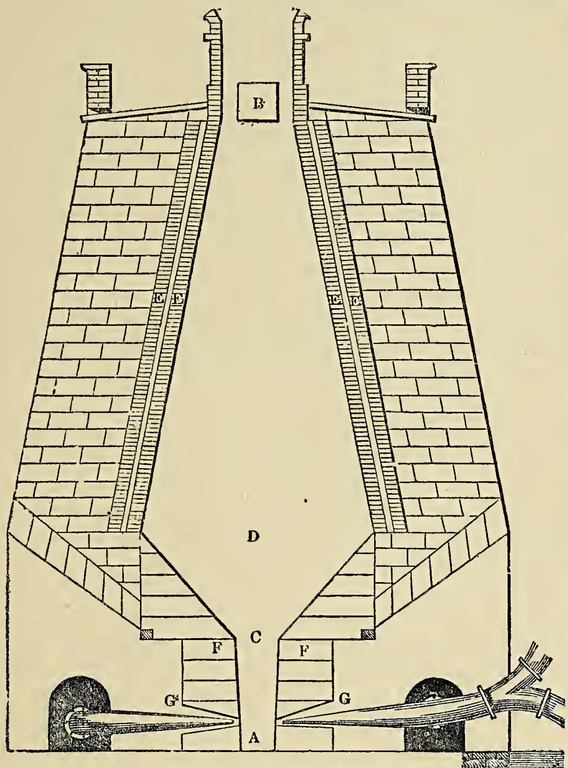


Fig. 3.—Pig-Iron Furnace.

Lead is a metal which is obtained in comparative ease from its ores, as it readily parts, at a moderately high heat, with the oxygen and sulphur contained in them. In many parts of our country may be found long narrow clefts in the rocks that tradition assigns to have been left by the Romans as the result of their lead-mining operations. Singularly enough, they adopted the plan of stamping or marking the pigs of lead, a plan still in use in this and other countries. As a matter of curiosity, we give the following illustration (Fig. 4) of the plan and section of a Roman pig of lead, which much resembles the form we now adopt. It was found in the North of England, where lead-mines are still worked.

The want of fuel has already been alluded to as a limit to the carrying out of any extensive metallurgical processes. It was remarked by a writer in 1678, that the country formerly bore very stately oaks in the Forest of Dean, "which are at this time nearly destroyed by the extension of the iron-works." About the period just referred to, and going on to the commencement of the eighteenth century, attempts were made to substitute coal for charcoal. "They once tried pit-coal, but with bad success," is related in a paper of the *Philosophical Transactions* of the Royal Society for 1693. In 1740, for the whole year, only 17,000 tons of iron were produced in Great Britain, from fifty-nine furnaces. In 1880, ninety-five furnaces in the Cleveland district alone produced 200,000 tons in a month, and this is entirely independent of the Scotch, Yorkshire, Lancashire, Welsh, and other districts. Perhaps, in round numbers, the product in 1880 of pig iron might be reckoned at some 6,000,000 to 7,000,000 tons, against the 17,000 tons named above, in 1740, for the whole of Great Britain.

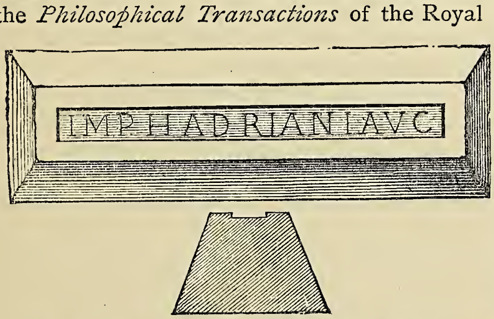


Fig. 4.—Plan and Section of a Roman Pig of Lead.

This indeed, shows how science benefits the arts and manufactures, how it enables us to utilise the riches which nature presents to us, and affords humanity so many of the benefits, comforts, and luxuries that modern civilisation requires.

But it is not only in our own country that such benefits have arisen. Belgium, France, Germany, and the United States of America, have each made similar advances in their production of iron from their various ores. Hence the inventor or perfector of a new process does not only occasionally enrich himself by his intelligent application of a knowledge of science, but spreads its advantages over the whole of the human race. Prominent among such men have been Cort,

Mushet, and Sir H. Bessemer, whose successes in these and other respects will be fully noticed and illustrated in succeeding chapters.

In respect to coal-mining in this country, its early history is involved in much obscurity. We may roughly guess that the Romans, Saxons, and Danes might have used coal as fuel. In 1239 the first charter for coal-mining was granted by Henry III., and about fifty years afterwards Newcastle-on-Tyne became noted for its "sea-coal." About a century later it became a common article of fuel, and it was also exported, although at the early part of the fourteenth century its use had been prohibited, because of its smoke vitiating the air. It is curious that some 500 years afterwards "Smoke Acts" were passed by the British Parliament to similarly abate the smoke nuisance arising from factories in most of our large towns. But coal was too useful to be put under a ban. In the days of Queen Elizabeth the Corporation of the City of London was permitted to levy a charge on each chaldron of coals, which, in consequence of the fire of London in 1666, was raised from one shilling to three shillings per chaldron, in or about 1667. Strange to say that these coal duties exigible by the City Corporation, are still demanded, and form a considerable item of its revenue. To give some idea of the enormous increase of the use of coal, it may be stated that half a century ago the annual consumption was about 15,000,000 tons. London alone now takes annually about half that amount, and the entire consumption of the kingdom at the present day is rapidly approaching 150,000,000 tons per annum, as already stated.

Into the methods of coal mining we shall not enter here, as they will subsequently be fully considered in practical detail. Our sources of coal in the United Kingdom are very extensive, and the character and quality of the fuel greatly vary, according to the districts from which it is obtained. Lanarkshire and other districts in Scotland supply a vast quantity. In England, we have the Lancashire, Durham, Newcastle, Yorkshire, Derbyshire, Staffordshire, and many other beds. All these districts afford coal of a bitumenous character, that is, such as will afford both light and heat. But in Wales, &c., another variety called anthracite is met with, which is chiefly constituted of carbon, and gives an intense heat, but no smoke in burning. Another curious variety is that called *cannel* or *candle* coals, which may be set fire to like wood, containing a large amount of hydro-carbon, and especially valuable in making the best kind of coal-gas used for the purposes of artificial illumination, and sold under the name of Cannel-gas.

We next turn to iron products, more especially that of *Steel.* Pig iron, or that form of iron which is produced by the smelting of the ores, as already described, contains many impurities, such as carbon, silicon, &c. These, with phosphorus, tend to render it unfit for most purposes, and, in fact, even the best pig iron can only be used for casting purposes, so far as it is produced in this country. Swedish ores, those of Barrow-in-Furness, &c., produce excellent pig fitted to make malleable iron and steel, but those of Cleveland and some other districts have been until lately, quite unfit to produce steel. The improvements and inventions that have recently been brought out to obviate these difficulties will be noticed subsequently.

Before the invention of the Bessemer process two operations were especially necessary to convert the raw pig-iron into the malleable material, and also into steel. For the first purpose the first process was that of *refining* the raw material, and this was followed by puddling. A furnace is constructed specially for the refining process. It has a hearth of fire-bricks, with cast-iron sides that are hollow, so as to allow a stream of water to pass through them, and thus keep down their temperature. At the sides of the furnace are doors, by which the pig and fuel are thrown in, and a powerful draught is caused by a chimney over-head. The pigs are first introduced, and then on them coke and slag are placed. By means of an air-blast, similar in principle to that already described in connection with the smelting furnace, a powerful current of air is driven in, and the heat raised until the pig-iron is melted. The molten metal is then run out into moulds, and cold water cast over it; the sudden cooling thus effected tends to render the metal very brittle, and to be easily broken up into fragments for the next operation.

This is called puddling; and to carry on the operation a reverberating furnace is employed. The construction of this is such that the flame arising from the burning fuel can be cast down, or reflected by an arched roof, on the metal placed beneatl. it. The following cut exhibits a section of one of these; but it must be stated that the shape is subject to several modifications, constantly introduced, and often the subject of fresh patents. Fig. 5, however, represents the principle of them completely. At A we notice the grate of the furnace, from which the flame

passes, in the direction of the arrows, to a high chimney, H, the draught of which is regulated by a damper, either placed as shown in the cut, or else at the top and external part of the chimney, where it is regulated by means of a rod that reaches to the ground, and by which the damper can either be raised or lowered, like a lid; C is a wall, or bridge, which separates B C, the hearth in which the pig-iron is placed, from the fuel in the grate A. Over these is the arched roof, E F, by which the flame is reflected or driven down on the metal placed on the hearth between B and C; and *a* is an opening at the side, by which materials are introduced or withdrawn: its position, however, in the side or ends of the furnace is varied.

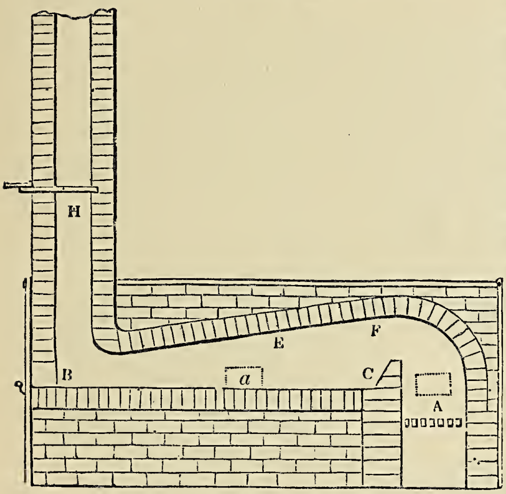


Fig 5.—Reverberating Furnace.

The iron, as obtained from the refining furnace, being broken into fragments, is spread on the hearth, and the flame of the fuel is caused to impinge upon it. As the iron softens, the puddler, by means of a long bar, inserted at the front of the furnace, constantly stirs up the material, so as to equalise the action of the flame until the whole is melted. By constant stirring, after this is effected, the melted mass becomes pasty, owing to a loss of carbon that is essential to its fluidity, and which, uniting with the oxygen of the air, passes off as carbonic acid gas. The iron gradually agglutinates, and loses all tendency to fluidity after the carbonaceous matter, &c., has been burnt or oxidised away.

As soon as the puddler judges this result to have been accomplished, his next duty is to convert the mass into separate balls, called blooms, each averaging about sixty pounds in weight—an operation not only exceedingly laborious, but requiring much skill and experience to perform properly. The ball completed, and glowing hot, is instantly conveyed to another part of the works, to be beaten by the shingling hammer. This consists of a long lever, at the end furthest from the fulcrum of which a mass of iron is fixed; the whole weighing some tons. The bloom, being placed on a kind of seat or anvil, is now repeatedly struck several times a minute by the hammer, which is itself lifted up by means of teeth or projections, that raise it by the action of a powerful steam-engine. As soon as the tooth escapes from touching the end of the shorter portion of the hammer extending from the fulcrum, the hammer end falls with immense force or momentum on the bloom, completely flattening it. The bloom is continually turned round, so as to expose all parts to the action of the hammer; and, eventually, attains an oblong form. By this hammering process many solid impurities are actually driven out of the iron.

Fig. 6 represents the puddler at work before the puddling-furnace, and the shingling-hammer just referred to. The latter, now in use, are of a similar construction to the steam-hammer which is employed for forging large masses of wrought iron, and will be fully illustrated and described in our subsequent remarks on the details of the iron processes.

It will be evident from what has been stated that by the processes of refining and puddling the pig-iron is converted from a brittle to a malleable state, and thus is capable of affording us plates, sheets, bars, hoops, angle-iron, rails, and many other forms of material used in our machine and other manufactures, but still it requires certain other processes to convert it into steel. By the brief description that we have given of the method of converting iron ore into malleable iron, it will be perceived that the series of processes involve many important laws of chemical science. In the first place, we have the ore in its crude or raw state, by no means uniform in quality or constitution. The iron is united, in all cases, primarily with oxygen, in respect to most of the ores employed, being either in a state of protoxide or sesquioxide. Very frequently the protoxide is united with carbonic acid, forming a carbonate of the metal, especially as found in the Cleveland districts of this country; and in those circumstances, as we shall hereafter more particularly notice, an additional cause of difficulty in its reduction occurs. But besides what we may call the legitimate combinations of iron with other substances, such as we have just referred to, external and abnormal impurities are present in most ores—as

alumina, silex or flinty matter, magnesia, lime, sulphur, phosphorus, &c. All these must be carefully removed before a really good, soft, ductile, malleable, and tenacious or fibrous iron can be produced—the last condition being indicative of the perfection of the iron; for the nearer it approaches to a crystalline condition, the more is its quality deteriorated.

It is to Sir H. Bessemer that we are indebted for, perhaps, the greatest improvement that

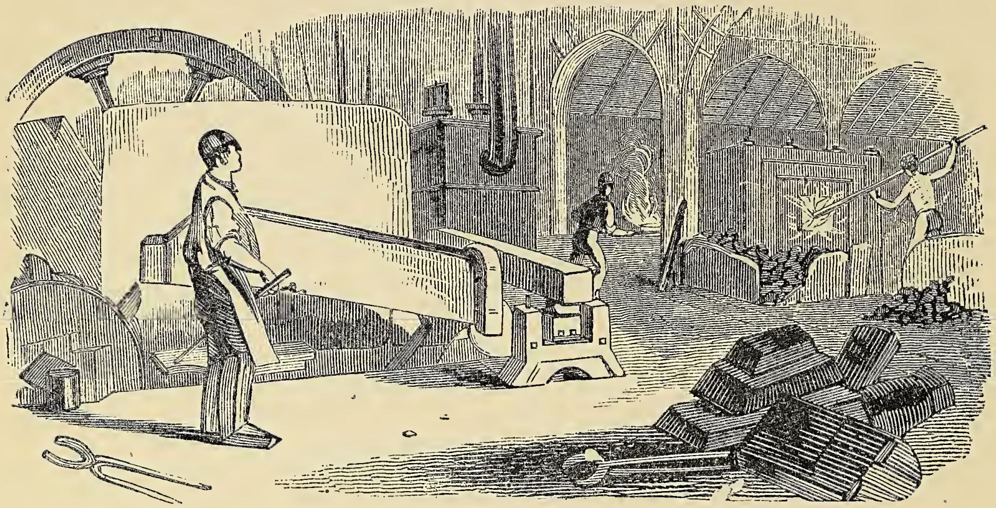


Fig. 6.—Puddling Furnace and Shingling-Hammer used in the Iron Manufacture.

has yet been introduced into the manufacture of malleable iron and steel, directly from the pig. It fortunately occurred to him, or, more properly, after an elaborate and very patient series of experiments, he discovered that pig-iron could be made its own refiner and puddler, and this is effected by availing of the carbon contained in the pig, causing its intense combustion, and consequent rapid oxidation, by sending a powerful blast of air through a molten mass of iron contained in what is called a *converter*.

Fig. 7 represents this arrangement. A is the body of the vessel, lined with fire-resisting materials. B, the support, and C the blast passing out of the molten iron. Into the latter the air is forced at a high pressure, and we here quote Sir H. Bessemer's own words on describing the process, and the effects that ensue:—

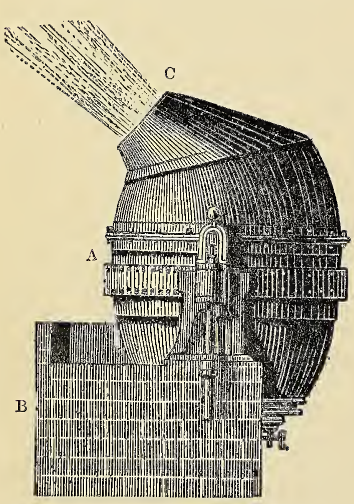


Fig. 7—Bessemer's Converter.

"The blast rushes up into the fluid metal from each of the forty-nine holes of the tuyeres, producing a most violent agitation of the whole mass. The silicium, always present in greater or less quantities in pig-iron, is first attacked, and unites readily with the oxygen of the air, producing silicic acid (pure flint); at the same time a small portion of the iron undergoes oxidation; and hence a fluid silicate of the oxide of iron is formed, a little carbon being simultaneously burnt off. The heat is gradually increased until nearly the whole of the silicium is oxidised, which generally takes place in about twelve minutes from the commencement of the process. The carbon of the pig-iron now begins to unite more freely with the oxygen of the air, producing at first a small flame, which rapidly increases; and, in about three minutes from its first appearance, a most intense combustion is going on; the metal rises higher and higher in the vessel, some times occupying more than double its former space; and, in this frothy liquid state, it presents an enormous surface to the action of the air, the oxygen of which

unites rapidly with the carbon contained in the crude iron, and produces a most intense combustion; the whole mass being, in fact, a perfect mixture of metal and fire. This carbon is now burnt off so rapidly as to produce a series of harmless explosions, throwing out the liquid slag in great quantities; while the combustion of the gases is so perfect, that a voluminous white flame rushes from the mouth of the vessel, illuminating the whole building, and indicating, to the practised eye, the precise condition of the metal inside. The blowing may then be left off whenever the number of minutes from the commencement, and the appearance of the flame, indicate the required quality of the metal. This was the mode usual in working the process in Sweden, but it is preferred to continue blowing the metal beyond this stage until the flame suddenly drops, which it does just on the approach of the metal to the condition of malleable iron."

The question now is how this newly-formed malleable iron can be converted into steel. The old and now frequently adopted method of producing steel is that of carburising the best wrought-iron bars. In other words, the pig-iron is deprived, to the utmost possible extent, of all its carbon by refining and puddling; and, subsequently, carbon is added to it by different processes. One is that of packing bars of the wrought-iron in cases of fire-bricks, with charcoal, and exposing them to a white heat for some days—a period reaching, in all, to nearly three weeks. By this the carbon of the charcoal gradually and superficially unites with the iron, producing what is called, from its appearance, "blister-steel." This addition, or rather re-addition of carbon restores the fusibility of the iron, previously absent in the wrought-iron state, for reasons already given, when we described the rationale of the puddling process in obtaining wrought-iron. The bars are broken in pieces, and sorted, for their quality is very irregular. The pieces are then put into refractory crucibles, and exposed to a high heat until complete fusion is effected. The melted steel is then poured out into iron moulds, and produces ingots of cast-steel. Even for small operations, the results of this method are extremely irregular; but if large masses of steel are to be produced, the difficulty is enormously increased, because it is all but impossible to keep up a sufficient supply of the melted metal to produce a really homogenous mass. The operation is, therefore, not only very costly, but exceedingly uncertain in its results. The carbon is unequally absorbed in the first instance, and possibly nitrogen, that is believed to be a constituent of good steel so produced, is irregularly, if at all distributed. The methods of carburising iron on the small scale are such as involve the use of blood, or prussiate of potass (ferrocyanide of potassium), both of which afford carbon and nitrogen, the latter-named salt giving these two elements in the form of cyanogen, a carbide of nitrogen.

Now this tedious, uncertain, and expensive process—and, we may add, almost impossible process for large castings or masses of steel—kept up the price of this article, for years, to a sum varying from £40 to £100 per ton. We now turn to the Bessemer process by way of pleasing contrast.

Sir H. Bessemer's first plan of converting soft iron, as prepared by his process already described, was that of having the converter filled with the molten metal, and to add a proportion of charcoal, pig-iron containing the necessary quantity of carbon, and thus any amount of carburisation could be produced. The subsequent use of Manganese and Spiegeleisen more effected still greater improvements. But here we must not anticipate the details of the present Bessemer process, as they will be fully dealt with hereafter. Our present object is simply that of tracing the rise and progress of ths Useful Arts and Manufactures.

It is almost needless to add that Sir H. Bessemer's process completely revolutionised the iron and steel trades, and, in most instances, displaced the old methods of their manufacture. He received from almost every civilised state, medals, &c., in honour of his invention, and in a pecuniary point of view his success was enormous. In a speech delivered in 1880, he stated that he had realised considerably over a million sterling by his inventions. Early in October, 1880, he was presented with the freedom of the City of London, as the third discoverer who had received that honour from the Corporation, the other two having been Dr. Jenner, who introduced the practice of vaccination, and Sir Rowland Hill, the originator of the penny postage system.

The casket, containing the documents of the granting of the freedom is represented by Fig. 8, drawn from the original. It is surmounted by a figure of Commerce pointing with her right hand to a Bessemer converter, while on the othei hand is a stack of pig-iron. On the

rounded surface at the ends of the cover are vignettes in repoussé work representing respectively a London and North-Western locomotive, built entirely of steel, and a steel built vessel. The centre panels of the lid carry at the sides medallions containing the Bessemer arms. Across the lid, dividing the curved ends from the central panel, run mouldings of polished steel representing a twisted steel rail, while a similar ornamentation is carried around the top of the casket and down each of the columns which divide the panels. In the panel on one side of the body of the casket is a similar medallion carrying the inscription, while on the other side is a copy of the medal which is annually given by Sir Henry Bessemer to the Iron and Steel Institute. The end panels contain the arms of the City in enamel, supported by dragons on high relief, while below are overflowing cornucopia intended to illustrate the success attendant upon the vast development of the steel manufacture which Sir Henry Bessemer's inventions have brought about. At the sides the bust carries medallions engraved with Sir Henry Bessemer's monogram, while the whole casket appropriately stands on a plateau of highly polished Bessemer steel. (See Fig. 8).

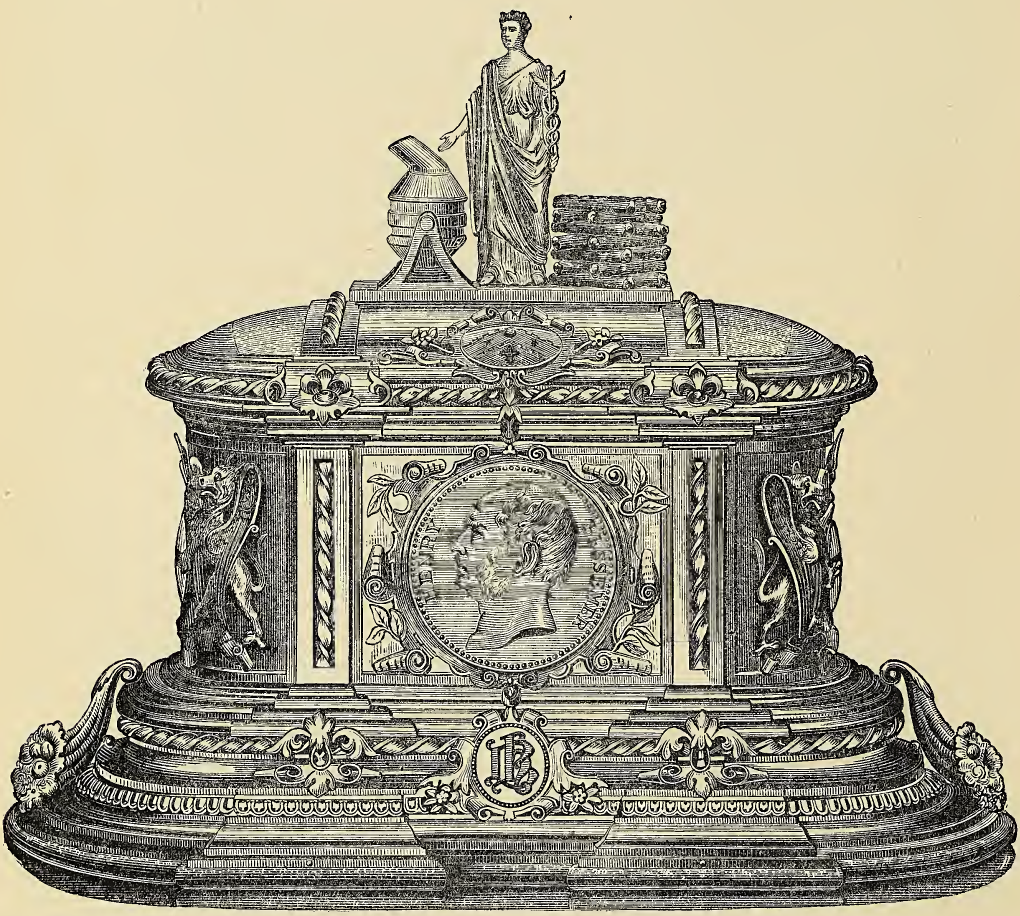


Fig. 8.—Casket, containing present to Sir H. Bessemer, by the Corporation of the City of London, in October, 1880.

Perhaps we cannot better describe the results of Sir H. Bessemer's invention than by quoting his own words, from a speech which he made on receiving the freedom of the City. He remarked as follows :—

"In the address of your honourable Chamberlain some mention has been made of the advantages resulting from the employment of steel for railway and other constructive purposes; and perhaps it would not be out of place if I were to explain to you as briefly as possible how it is that steel can now be made in the short space of fifteen or twenty minutes, instead of requiring from two to three weeks as formerly, and why it now costs only £6 or £7 per ton, instead of £50 or £60." After giving a detailed description of the mode of manufacturing steel under the old system, Sir Henry continued as follows.—"Under the process which I had the honour of inaugurating, we dispense with every one of the intermediate processes formerly employed. We have no smelting of pig-iron, we have no puddling, we have no making of balls, we have no rolling of bars, we have no shearing of bars, we have no tying up, we have no heating furnaces for blasting operations. You will readily understand why with a process so rapid and so entirely devoid of the use of expensive fuel, and of all those various skilled manipulations which were necessary at every stage of the old process, the cost of manufacture is so exceedingly small as it is found to be. I have lately seen at the large works of Sir John Brown twenty tons of crude cast iron converted into twenty tons of cast steel in the small space of twenty-three minutes. The value of that material, taken at £4 per ton, would be £80 at the commencement; its value after conversion at that particular time could not have been less than £100 per ton, or £2,000 altogether. This is, of course, an exceptional case; but it is a fact. At the time when my invention was introduced into Sheffield, the entire make of steel was 51,000 tons in the year; last year (1879), we had 830,000 tons of Bessemer steel, being sixteen times what was before the amount of the whole produce of the country. It is anticipated that on the continent of Europe this year's make (1880) will reach 2,000,000 tons, and our own 1,000,000 tons. The value of these 3,000,000 tons together may be taken at £10 per ton, or £30,000,000 sterling; and if that metal had been made by the old process which I have described, it would have been impossible to have brought it into the market under £50 a ton, or £150,000,000 sterling."

We have already drawn attention to the difficulties of carrying on the early production of iron owing to the want of fuel (see *ante* page v), and in confirmation of our statement we quote Sir H. Bessemer's remarks, delivered on the occasion just referred to, on this subject:—

"When I reflect, gentlemen, on the events of the day, my mind is instinctively drawn to the contrast between my own lot and that of the great pioneers of old, whose labour and talent laid the foundation, and whose energy and perseverence reared the mighty fabric of the British iron trade. If we look back to the days of Queen Elizabeth, we find that Sussex was the chief seat of the iron manufacture of this country. Numerous small furnaces were scattered over Sussex, Kent, and Surrey; and, although the production at that period did not exceed 17,000 tons annually, the vast forests that previously existed had been cut down to supply fuel for these numerous works. So great, indeed, was the destruction of timber, that the Government, in alarm lest the supply of oak for ship-building should be exhausted, passed the most stringent laws for its protection. No tree of only one foot in diameter was allowed to be cut down under severe penalties, and no timber of any kind whatever was allowed to be cut within twenty miles of the City of London. These and other restrictions greatly discouraged the manufacture, and reduced the production of iron. While the trade was at this low ebb a most important invention was made in 1640 by Dud Dudley, of Tipton, by means of which iron was successfully smelted with mineral fuel. It is impossible to over estimate the advantages which the world has gained by this important discovery. Poor Dudley did not rest on a bed of roses. The whole trade rose up against him as their natural enemy, who, they said, was bringing ruin and destruction on their already-declining industry. His works were pulled down by a riotous mob; his patents were evaded; large sums of money were expended by him in the attempt to secure his rights; and he was at last cast into prison for debt. How many hundreds of the intelligent and persevering men to whose inventions we owe the highly developed state of the iron manufacture have shared with Dudley the misfortune of being an inventor, while comparatively few have reaped a rich reward for the services they have rendered to the country!"

We must next glance at the rise and progress of manufactures in iron and steel, a subject of immense importance to mankind, because, however highly we may conventionally hold the precious metals, as gold and silver, they are as dross compared with the practical value of iron, and the so-called base metals.

The first question that has to be discussed in this department of the history of the Useful Arts and Manufactures is that of motive power. In the early history of the world manual labour

seemed to have been alone available, and the erection of the pyramids of Egypt, and the obelisks of the Cleopatra needle, now in London, and that conveyed in 1880 to the United States, show that the power employed must have been enormous, and must necessarily have been the direct work of men, so far as the moving power was concerned. In removing the raw material of which these monuments of history are composed, it is most probable that rafts may have been used; but still there remains the difficulty to be explained as to how these rafts were loaded and unloaded. With all the appliances of modern civilisation, the removal of the Cleopatra Needle from Alexandria to London in 1878, taxed the utmost resources of our engineers. Yet its material, and the obelisk itself, must have travelled several hundred, perhaps thousands of miles before it found a rest on the shores of Northern Egypt, under the old methods of civil engineering.

Water and wind were doubtless the first sources of motive power to the ancients, and water especially was used as a means of transit. If we take the history and topography of all the chief places in the world, savage and civilised, water, water-carriage, and perhaps water power have been the secrets of their progress and development in commercial and social centres. At the present time we make an additional use of our rivers; it is that of converting them into common sewers for the purpose of conveying our refuse of domestic and manufacturing economy to the sea if possible, if not to the annoyance and danger of every town situated on their banks.

A falling or rising tide would of course, suggest the use of the flowing water as a source of motive power, and in the absence of the tide, the natural flow of the stream from its source to its mouth, or to the commencement of the tidal limits, would naturally be used for similar purposes. The invention of the steam-engine has caused the almost general neglect of these uses of water, and consequently water-wheels in this, and many continental countries, have for a long time past been falling into disuse. The same may be said in regard to wind-motive power, the wind-mill gradually becoming a thing of the past. In holy writ we learn that the motive power for corn-grinding was generally that of the human hand. "Two women shall be grinding at the mill, the one shall be taken and the other left." (Matt. xxiv. v. 41.) Probably the first mode of grinding corn, was to place the grains on one stone and strike or rub them with another. The general character of these ancient hand mills or querns is shown in the annexed cut (Fig. 9), where *a* is the two stones, one on the other; *b*, the upper stone above; and *c*, the lower stone alone. The concavity of the upper stone fits the convexity of the lower; and the corn, after being introduced at the central hole in the upper stone, rolls over the convex surface, and is ground in its passage. There is a spindle to connect the two stones, and a handle to the upper one, by which it is rotated. Such is the simplest form of the hand-mill, which has exhibited many varieties at different times. Dr. Clarke, when travelling through Nazareth, witnessed a scene which strikingly illustrated the Scripture passage above-mentioned "two women grinding at a mill." There were two women seated on the ground, opposite to each other, holding between them two round flat stones; in the middle of the upper stone was a cavity for pouring in the corn; and by the side of this, near the rim, was an upright wooden handle for moving the stone. The operation began by one of the women, with her right hand, pushing this handle to the other woman opposite, who sent it round to her companion. By this means a circular and rather quick motion was communicated to the upper stone, while with their left hands the women supplied the mill with corn, to replace that which had been ground into flour.

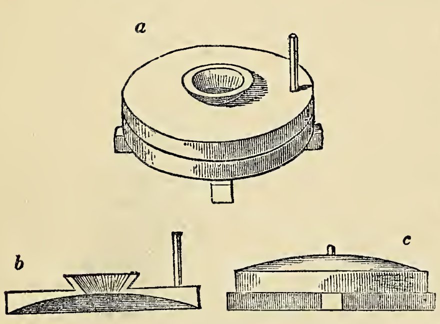


Fig. 9.—Ancient Hand Corn-mill.

This would certainly be slow work, and for want of other motive power, the production of bread would be limited to the hand-power, generally women of each household. It is more than probable, however, that the horse and other domestic animals might have at last been used to replace human labour.

In irrigating the fields in warm climates for assisting the growth of the crops, when the

adjacent stream is below the level of the fields, especially in regard to the cultivation of rice, early in China, two modes prevailed. In one of these, two men stood on opposite sides of a stream, each holding a string, by which a vessel is suspended over the middle of the stream; by slackening the cords, the vessel was made to dip into the water; by swinging them in a peculiar way, it was filled with water; by tightening them the vessel was brought up to the level of the ground; and, lastly, by jerking them, the vessel was made to pour out its contents on the neighbouring fields. The other method was more efficacious. There was a kind of quadrangular trunk, extending obliquely and upwards from a stream or pond, to a field which was to be irrigated, and a number of square boards, just fitting the width and depth of this trunk, passed up through it when pulled by a chain, thereby forming a number of cells capable of raising the water. Two or three men worked a kind of tread-wheel, by which the chain was wound up, and in its progress the boards attached to it drew or carried up water from the lower to the higher level.

The application of motive power for manufacturing purposes other than that of human labour is comparatively recent. In our country water-power seems first to have been used, after that of the animal, such as the horse, &c. In fact, the present names of two distinct methods of spinning cotton yarn produced at the present day—water-twist, and mule-spinning—indicate the sources of power employed at the time of their origin, although, of course, steam has long ago superseded such sources of power. But even within our own remembrance, animal power has been employed in the factory, and it is only about forty years ago that we witnessed the trial of a high pressure steam-engine which had been recently introduced in place of the old condensing steam-engines in one of the great centres of our cotton industry. Within the same period we have known steam-vessels on the Thames, in the boiler of which a pressure of some four to six pounds on the square inch was employed, and, of course, little power was developed by large engines. Now a pressure of from forty to one hundred pounds per square inch is employed, and in locomotives even 200 lbs. per square inch is used. Consequently, we can now create a motive power by steam machinery, occupying only a few square feet of surface, equal to that of a thousand horses, which would cover over an acre, if it were possible to employ such a source of force.

The history of the steam-engine and its progressive development, we can only briefly discuss at present. Its earliest form was certainly of the crudest character, and involved an immense loss of fuel. The first object to which it was proposed to be applied, was that of moving vessels in water. The honour of having first made this suggestion is claimed by the Marquis of Worcester, an ingenious nobleman, who wrote a work called the "Century of Inventions," in the reign of Charles II. One of these inventions, he describes, as enabling him "to make a vessel of as great a burthen as the river could bear, to go against the stream, which the more rapid it is, the faster it shall advance; and the movable part that works it, may be by one man, still guided to take the best advantage of the stream." It is supposed, and it is highly probable, that the Marquis had in view some kind of steam-engine as a motive power, but his description is too vague to give any idea on the matter.

Papin in France, and Dr. Allen in England, severally suggested the use of steam as a moving power for boats, but neither of them reduced their theory to practice. The same may be said of Jonathan Hulls, who, in 1736, published a work suggesting it; but he had the merit of entering much more fully on the subject. This work was entitled a "Description and Draught of a New Invented Machine, for carrying Vessels or Ships out of or into any Harbour, Port, or River, against Wind and Tide, or in a Calm." His proposal consisted in placing a steam-engine, then known by the name of an "atmospheric engine," in the tug-boat, and communicating the power by means of ropes to the axis of a kind of paddle-wheel, mounted on a frame-work projecting from the stern of the vessel.

The first parties in this country, who, to a certainty, practically demonstrated the feasibility of steam navigation, were connected with Edinburgh and Glasgow. In 1787, Mr. Miller, of Dalswinton, constructed a boat, which was to be moved by paddles, worked by men or horses; but having had his attention drawn to the possibility of using steam for the purpose, he availed himself of the services of Mr. Symington, an engineer of Glasgow, to put the idea to the test. The first experiment was that of using a double boat, containing a steam-engine on one side, a boiler on the other, and a paddle-wheel between the two boats. This little contrivance was so far successful as to travel through the water at the rate of five miles per hour. The

next experiment was in the large boats used on the Forth and Clyde canal, one of which was made to travel at the rate of seven miles an hour. As a commercial matter, these experiments led to no immediate result in this country. It was not until 1813 that a steam-boat for passenger traffic was permanently established on British waters.

Meanwhile, whatever may have been the relative merits as to inventive powers, America has the credit of first plying steam-boats for hire. Fulton, after witnessing Symington's experiments in Scotland, constructed a small steam-boat for the Seine in 1803. Three years afterwards he commenced building a steam-boat on the river Hudson, in America, which was launched in the spring of 1807. In the August of the same year, the vessel started on her first voyage. This attempt of Fulton was the opening of the career of steam navigation in America. Meanwhile, Mr. Henry Bell, who had been instrumental in obtaining information in Scotland for Fulton, put in operation a system of steam navigation on the river Clyde. In 1813, he started a little boat called the *Comet*, which plied as a passage boat. It was about forty feet long, and ten feet wide, its measurement was about twenty-five tons, and it was worked by a little engine of three-horse power.

The cut (Fig. 10) represents the engine; it narrowly escaped destruction during the fire that destroyed the Polytechnic Institution at Glasgow, in 1857, and is now in the collection of the University of Glasgow.

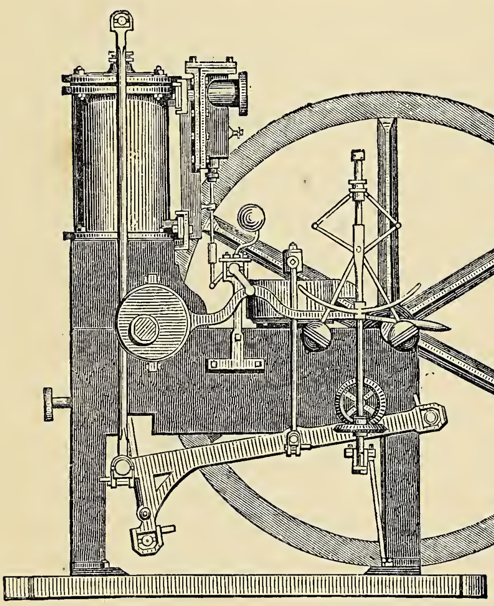


Fig. 10.—Bell's Engine in the "Comet."

In the following engraving (Fig. 11), will be found an illustration of the engine and boiler of the steamboat "Clermont," built in 1807, already referred to, as designed by Robert Fulton. From a work by Robert H. Thurston, we extract the following information in respect to the history and labours of Fulton, in addition to what have been stated :—

"Robert Fulton was born in Lancaster County, Pennsylvania, in 1765; educated as a watchmaker, he early developed both artistic and mechanical tastes, and, as a protégé of Benjamin West, he came to England to study painting about the year 1785. This profession he abandoned about eight years later for that of an engineer, especially devoting himself to the construction of torpedoes and torpedo vessels, and later to the mechanical propulsion of vessels. He found Mr. Robert Livingston, who in 1801 was the American ambassador in France, one of his most valuable advisers and influential friends, and it was in or near Paris, that he made his first working model of a side-wheel boat, which was experimented with on the Seine in 1802. This first experiment was a failure, the vessel giving way under the weight of the machinery, and another hull, sixty feet long and eight feet beam, was built, and the engines placed in it. The first experiments with this vessel were made on the Seine in July, 1803, when a speed of four and a-half miles was attained; the trial, however, attracted but little attention in France, and Fulton came to England in 1804, where he prepared plans for new engines that were constructed by Boulton and Watt, being completed in 1806, when Fulton returned to the United States, taking the machine with him. Arrived there, he, in connexion with Mr. Livingston, who had also returned to America, built a boat 133 feet long, 18 feet beam, and 9 feet in depth; the machinery was placed on board, and the first trial trip was made in August, 1807, between New York and Albany, the distance of 150 miles being made in 32 hours by steam alone. The engines fitted to this vessel were made by Boulton and Watt; they had vertical

cylinders 24 inches in diameter, and 4 feet stroke, the crossheads of the piston rods being connected to side levers attached to bell-cranks, which transmitted the motion, through gearing, to the paddle-wheels, which had floats 4 feet long, and were immersed 2 feet. The illustration (Fig. 11), is copied from Fulton's own drawings. This was the inauguration of steam river navigation in the United States, and immediately after the trial trip just referred to, the 'Clermont' plied regularly between New York and Albany as a passenger boat. In the winter of 1808 she was enlarged and repaired, and two other vessels were added to the service. In 1812, Fulton built the first steam ferry boat between New York and Jersey City, and the next year two more were constructed for running between New York and Brooklyn. They were twin boats with parallel hulls decked over, and could each carry eight vehicles, thirty horses, and 300 or 400 passengers. They made the journey between New York and Jersey City in fifteen minutes, or only five minutes longer than the same journey requires to-day. Fulton's most interesting work, however, was commenced in 1812, when he designed a steam-propelled war vessel to have a speed of four miles an hour, and to carry heavy guns, some of which were to be discharged below the water line. The time taken in the building of this vessel was remarkably short; her construction was authorised by Congress in March, 1814, she was commenced the 20th of June following, and launched on the 29th of October of the same year. This vessel was called 'Fulton the First,' and the following are some of her particulars:—She was 156 feet long, 56 feet wide, and 20 feet deep, and she measured 2,475 tons. She was composed of two hulls placed parallel to each other about 15 feet apart, the space between being decked over. Her engine had a cylinder 40 inches in diameter, and 6 feet

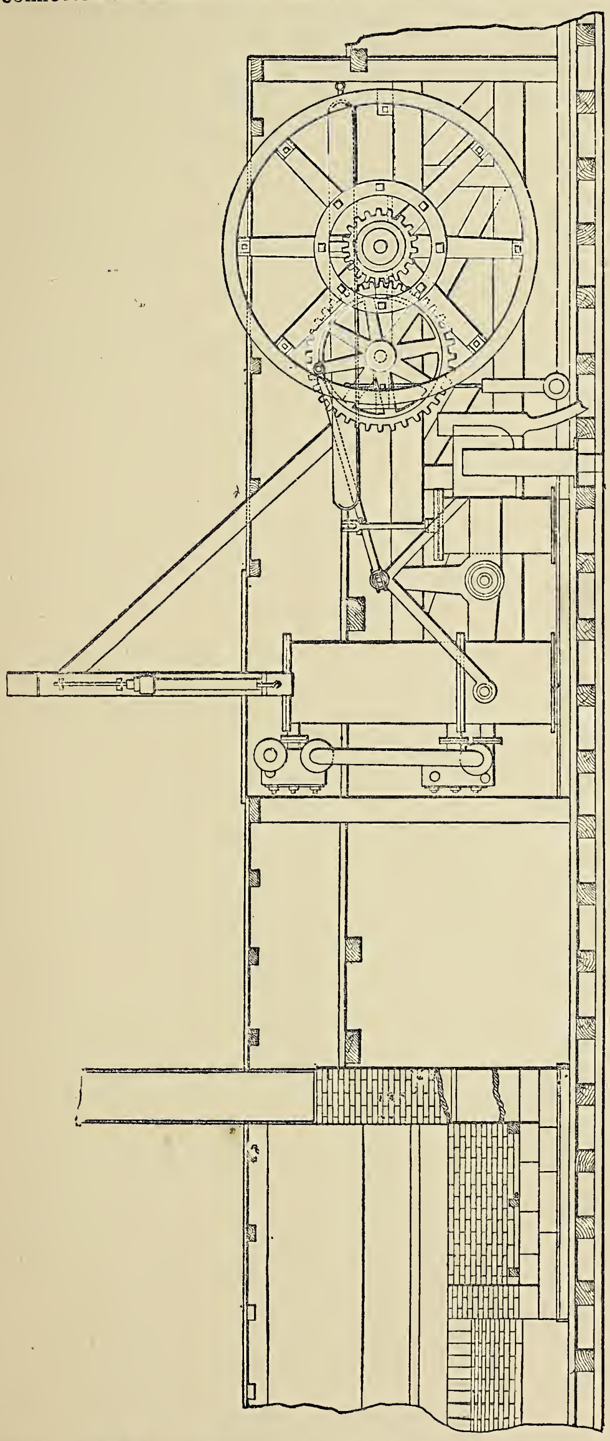


Fig. 11.—Engine and Boiler of the River Steamboat "Clermont," built in 1807, from Drawings by Fulton.

stroke, and steam was supplied from a copper boiler 22 feet long, 12 feet wide, and 8 feet high; the engine drove a wheel 14 feet wide and 16 feet in diameter, and having an immersion of 4 feet. The engine was placed in one of the hulls and the boiler in the other; the vessel was practically armour-clad, for the sides were 4 feet 10 inches thick, and the spar deck was protected by musket-proof bulwarks; she was armed with thirty 32-pounders, and designed for firing red-hot shot. The trial trip of this, for that time, truly formidable vessel took place in July, 1815, when she ran from New York to Sandy Hook and back, a distance of fifty-three miles in eight hours, and, at a subsequent trial, when the vessel was thoroughly equipped, her measured speed was five and a-half miles an hour. Robert Fulton did not live to see this triumphant conclusion to his important work, since he died on February 24, 1815."

It will be seen from the above notice of Fulton's labour, that he astonishingly anticipated the inventions of the present day, in regard to the application of steam as a motive power for water traffic. He seems to have had an idea of torpedoes, iron-clads, and other modern inventions, far in advance of the age in which he lived, and their requirements.

Having thus traced the sources of the metals chiefly used in the industrial processes, and the history of the motive powers at present employed, it will be next desirable that we should notice some of those useful arts in which science has given so much benefit to mankind, by substituting machines for human labour.

Prominent among such arts, is that of agriculture, for the first necessity of our lives is that of producing food, especially cereal crops.

Whatever opinion may be held in respect to the date of origin of any other branches of human industry, no one can dispute that agriculture must take the first place in the history of them all. From the day that the first curse was pronounced on man up to the last he will occupy this earth as a tenant, the labour of the plough and spade, of sowing and reaping, will continue, for such are the most important accessories of our existence so far as the body is concerned.

It would be invaluable to modern science and practice if we could trace the gradations through which the art has progressed. Ancient history, sacred and profane, but dimly acquaint us with what our earliest forefathers grew, and what art they practised in rendering the soil fertile. That there was "corn in Egypt," although only a matter of historical interest, as connected with the early days of the Israelites, to some readers, is highly suggestive to the man of science and the practical agriculturist. We may naturally inquire why that country at the moment abounded in the means of food; for, admitting the storage of immense quantities of corn by the foresight of Joseph, how can we explain the possibility of such a provision for the years of famine, except on the ground that agriculture had made great progress as an art, although a scientific knowledge of its conditions might not be possessed by the Egyptians of those days? Another and strong confirmation of this opinion, may be gained by pointing out that the grains of wheat found in the envelope of mummies, still retaining vitality after a lapse of 3,000 years or more, are amongst the most prolific species of our cereal crops.

It was not simply in the production of corn that the ancients excelled; horticulture was equally followed by them with the same success; hence we read of the longings for the cucumbers, and other garden products of Egypt, by the Israelites on their journey through the wilderness. It would seem that, from all accounts of ancient gardening, the gourd tribe was especially cultivated—such as the cucumber, melon, gourd, &c.; and this can be no matter of surprise when the heat of the climate in which the early inhabitants of this world lived is borne in mind. Such fruits are amongst the most refreshing in countries like Egypt, Arabia, Palestine, &c.; and to the present day are characteristic productions. The onion tribe was likewise largely cultivated, as numerous allusions in the Scriptures and secular early historians indicate.

Another evidence that the tilling of the soil has made rapid progress, is seen in statements that are made in respect to the use of manure. Thus, in the 2nd of Kings, a price of five pieces of silver was asked for the fourth part of a cab of dove's dung—undoubtedly the guano of those days. Referring on this point to China, we find in that country accounts of agricultural processes of ancient date, confirming the general knowledge of those principles and modes of practice that are now admitted by science to be the best for the production of prolific crops; and, without doubt, the abundance of leeks, onions, cucumbers, melons, &c., was then procured by the liberal use of the richest manure, just as is necessary in our day, in all countries, to produce the same result.

Coming down to a much later date—that of the Greeks and Romans—we find evidence of high culture, and much practical, indeed, scientific knowledge. The fact that Pythagoras forbade the use of broad beans to his followers, because they were "first cousins to man," is in exact accordance with the discoveries of modern science, which point them out as the most nitrogenised, or flesh-forming substances of vegetable growth. It is familiarly known to all, that nothing is "so filling" (to use a common, but expressive phrase) as broad beans; and this is because they contain so much nitrogen in their legumin. Pythagoras would, therefore, have more properly called them as "first cousins to flesh."

The Romans were especially noted for their advance in agriculture and horticulture. Pliny gives us many interesting details on the subject; and no one who has perused the *Bucolics* and *Georgics* of Virgil, will fail to perceive how high a rank, and perfect a practice, must have existed in respect to all pursuits of a farming character in those days. The Romans cultivated all the esculent plants, herbs, and fruits now esteemed in Europe, including cabbages, turnips, carrots, peas and beans, pot-herbs of numerous kinds, cucumbers, melons, &c., mustard, mushrooms, salads, apples, pears, walnuts, and other nuts, with a long list that cannot here be detailed.

At what period any branch of systematic farming was commenced in this country seems very uncertain. In the early history of Britain, its surface was abundantly covered with forest trees, and far more land was under water than at the present. The Thames, at that period, extended its bed over all the marshes of Essex, from near the Nore to far beyond London, and the Kentish banks; while those of Surrey were similarly overrun with water far inland. And it was not till embankments were raised, subsequent to the Roman invasion, that the rich land now so productive of corn, and every variety of vegetable food, was made capable of culture. The absence of such a bank, and its probable consequences, were aptly illustrated a few years ago, when the fearful gunpowder explosion at Erith occurred; for had not the gap occasioned in the bank been filled up, the results, for miles around, and even to some of the southern suburbs of the metropolis itself, might have been most disastrous.

There is no doubt that the greatest benefit that happened at that period to our country was its invasion by the Romans. The latter found barbarians as its inhabitants, only to be compared with such as, in modern days, were discovered in Feejee and the islands generally of the South Pacific Ocean; and what we have done for these, the Romans, in part, did for our ancestors. But it was chiefly to the religious emissaries of Rome that was due this introduction of systematic agriculture and gardening. Settling, as they did generally, on alluvial soil, and near the banks of some river or stream, they availed themselves of the natural fertility of such grounds; introduced long-established and generally successful methods; and so taught, by easy steps, our rude and roving forefathers the art of culture. Iona (supposed to be the earliest settled locality of Christianity in this country; known also as Icolmkill, and one of the western islands of Scotland) has afforded us traces of the ancient gardens. Dr. Walker remarks:—"On a plain adjoining the gardens of the abbey, and surrounded by small hills, there are vestiges of a large piece of artificial (ornamental) water, which consisted of several acres, and had been contrived both for utility and pleasure. Its banks have been formed by art into walks; and though now a bog, you may perceive the remains of a broad green terrace passing through the middle of it, which has been raised considerably above the water. At the place where it has been dammed up, and where there are the marks of a sluice, the ruins of a mill are still to be seen, which served the inhabitants of the abbey for grinding their corn. Pleasure-grounds of this kind, and a method of dressing corn still practised in these remote islands, must, no doubt, have been considered, in early times, as matters of high refinement."

But one of the greatest advantages that modern farming has reaped from science (excluding those afforded by applied chemistry), has been the introduction of machines for doing almost every kind of out-door work formerly effected by men, horses, or cattle. The two last are manageable animals, but not so man. Every farmer, necessarily, must keep a regular number of hands for the ordinary day-work of the farm; but at ploughing, sowing, reaping, and threshing seasons, he requires a great increase in their number. And not only so, every farmer requires such an increase at the same period; hence the demand for human labour often so far exceeds the supply, that soldiers in barracks adjacent to farms, have been frequently pressed into the service, especially at reaping-time. This great demand for labour, of course, induced the most capricious and extortionate demand in respect to its price. At certain seasons of the

year, we have seen the steam-vessels plying between the Irish and English coasts, literally crammed by natives of the Emerald Isle, coming over especially for the hay-making and reaping seasons—creatures that, apparently, had scarcely ever tasted animal food in their lives, and lived in hovels unfit for pigs. Yet, at the conclusion of the season, many of them will return home begging their way to the port on foot, although, perhaps, with £20 or £30 in their pockets.

Now all the inconveniences occasioned by the preceding causes have been either modified or removed by the invention of machines for nearly every operation of the farm—sowing, reaping, threshing, ploughing, &c. Portable steam-engines may be generally seen at work, at the present time, at most large farms—an innovation that would have horrified as well as terrified the former tillers of the soil. These machines do all the work less wastefully, and far better, than under the old method by man and animals. They require no food unless when at work; and hence they are highly economical, especially to those who are situated at some distance from any labour market.

The ground in its natural state, and in favourable conditions, such as is called "virgin soil," requires what is called *tilling*. It is not fitted for the reception of seed, but must be loosened, broke up, and otherwise prepared. The better the soil, the less is such a preparation needed, and consequently, where land is naturally very rich, the cultivation is generally of the most slovenly kind. Ireland, for example, has a rich soil, but its natural advantages have been but little utilised.

In the earlier stages of husbandry the spade, hoe, and rake were the chief implements of agriculture, but eventually the plough was invented, and is now in universal use. The object in using the plough is to cut up and turn over the surface soil, and for this purpose many mechanical contrivances have been invented, culminating in our day with the steam-plough.

The oldest form of the plough of which we have any record is that of a mere wedge, with a crooked handle to guide it, and a short beam by which it was drawn. The light Hindoo plough, used in many parts of India, differs very little from this form. There are certain technical names given to the parts of a plough, which must be understood before we can speak of their varieties. The *body* is that part to which all the rest is attached. The bottom of it is the *sole* or *slade*, to the fore part of which is affixed the *point* or *share*, the hind part of the sole being called the *heel*. The *beam*, which advances forward from the body, serves to keep the plough in its proper direction, and to the end of it are attached the oxen or horses by which is is drawn. Fixed in the beam in a vertical position, before the point of the share, with its point a little forward, is the *coulter*, which serves to cut a vertical section in the ground; while the point of the share, expanding into a *fin*, separates a slice by a horizontal cut from the subsoil or solid ground underneath. The *mould-board* or *turn-furrow* is placed obliquely behind the fin, to the right or left, in order to push aside and turn over the slice of earth which the coulter and share have cut off; it thus leaves a regular furrow wherever the plough has passed, which furrow is intended to be filled up by the slice cut off from the land by the side of it, when the plough returns. Wheels are comparatively a modern appendage to the plough, and are intended to support the end of the beam, to keep it at a proper level during the ploughing.

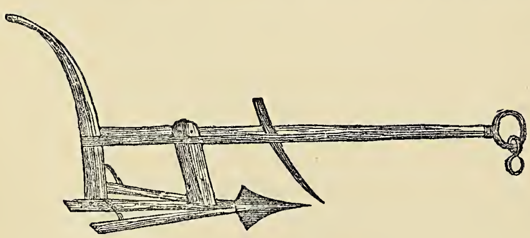


Fig. 12.—Roman Plough.

All the several parts have undergone improvements from time to time. The Roman plough (Fig. 12) consisted of a beam, a body, a share, and a handle or stilt; the office of the turn-furrow was performed by two pieces of wood, about six inches long, projecting obliquely upwards. The sole had two pieces of wood fixed to it on each side, forming an acute angle with it, in which the teeth were inserted. The teeth helped to push aside the earth to the right and left. A chain or pole, connected with the end of the beam, was hooked to the middle of the yoke on the neck of the oxen, and thus the plough went on making parallel furrows very near to each other.

Our Anglo-Saxon ancestors presented us with the first form of plough that we have notice of in our country. It is represented in Fig. 13, with a pair of oxen yoked to it. There is little doubt that in early days oxen were largely employed in ploughing the land. Numerous allusions

are made to the practice in Holy Writ, and in the profane historians of early ages. Asses seem occasionally to have been employed for the same purpose. Even in our own country we have seen oxen occasionally used in ploughing, and frequently as beasts of draught in the Midland and Northern counties.

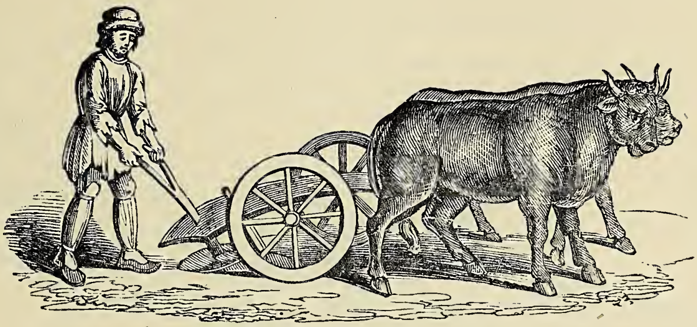


Fig. 13.—Anglo-Saxon Plough. (Harleian MS. No. 4374).

By way of contrast, we next turn to some of the most important contrivances employed for agricultural purposes.

The inventors of modern machinery may be simply called legion. From the plough to the stacking of corn, or the making of the hayrick, each process has become one of mechanical contrivance actuated by steam.

The following illustrations show some of the improvements above alluded to. Fuller details will be entered into under the head of Agriculture, our present purpose being only that of giving some idea of the character of the improvements that modern science has placed in the hands of the agriculturist.

The great object in ploughing the land is to bring to its surface soil that has hitherto not been the subject of cultivation. This becomes exposed to the chemical action of air and moisture, and so is made fit to receive the seed. A subsoil plough of superior construction has been patented by Messrs. Charles Burrell and Sons, agricultural machine makers, of Thetford, in Norfolk, to whom we are indebted for the following illustrations of ploughs and harrows.

Fig. 14 represents the patent subsoil plough, which is constructed and worked on the principle of a balance plough. Besides the ordinary ploughs attached to it, it is fitted with

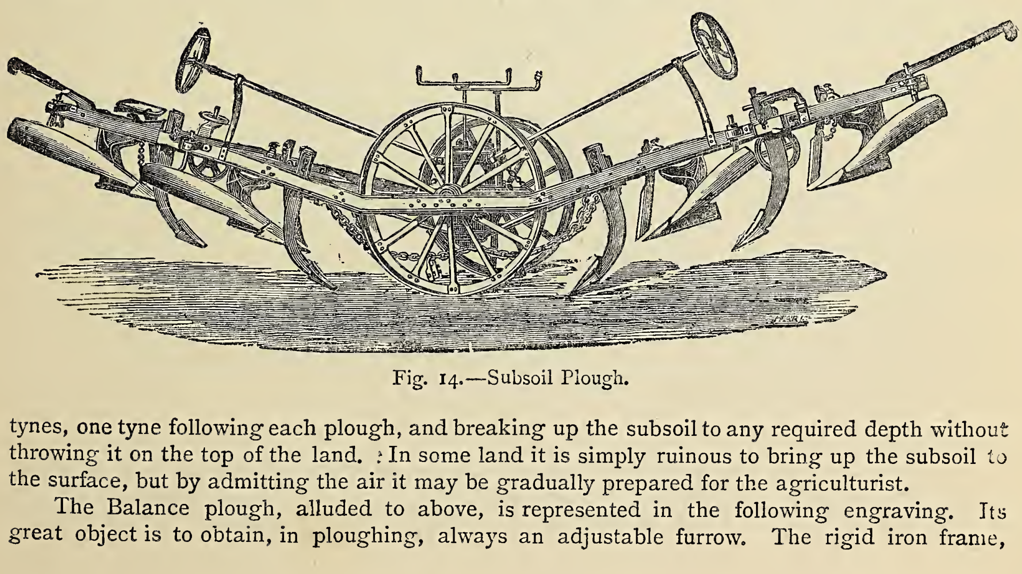


Fig. 14.—Subsoil Plough.

tynes, one tyne following each plough, and breaking up the subsoil to any required depth without throwing it on the top of the land. In some land it is simply ruinous to bring up the subsoil to the surface, but by admitting the air it may be gradually prepared for the agriculturist.

The Balance plough, alluded to above, is represented in the following engraving. Its great object is to obtain, in ploughing, always an adjustable furrow. The rigid iron frame,

which is so essential to all steam-driven implements, is maintained, and the alteration of the width of the furrow is effected by means of a wedge which throws the ploughs at different angles to the frame. This wedge does away entirely with bolts and screws, and renders the position of the ploughs thoroughly rigid; at the same time it affords the best means of altering the width

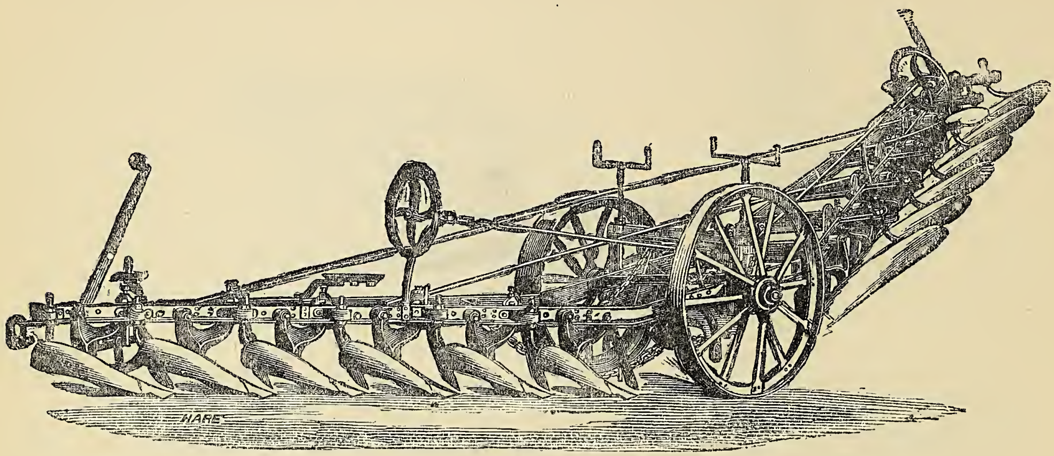


Fig. 15.—Patent Balance Plough.

of the furrows. By removing the ordinary mould-boards used for surface-ploughing, and substituting short ones for "digging breasts," a tillage can be effected quite equal, if not superior, to that obtained by spade husbandry, which leaves the land in the most desirable state for the action of the atmosphere. (Fig. 15.)

Another and important operation in treating the land is that of harrowing. In gardening will be found the simplest illustration of the harrow in the common rake, just as the spade is replaced by the plough. The following cut illustrates a steam-harrow. It is so constructed as to take in a breadth of from twelve to eighteen feet, and thus from forty to sixty acres of land can be easily gone over in a day by this application of steam-power. (Fig. 16.)

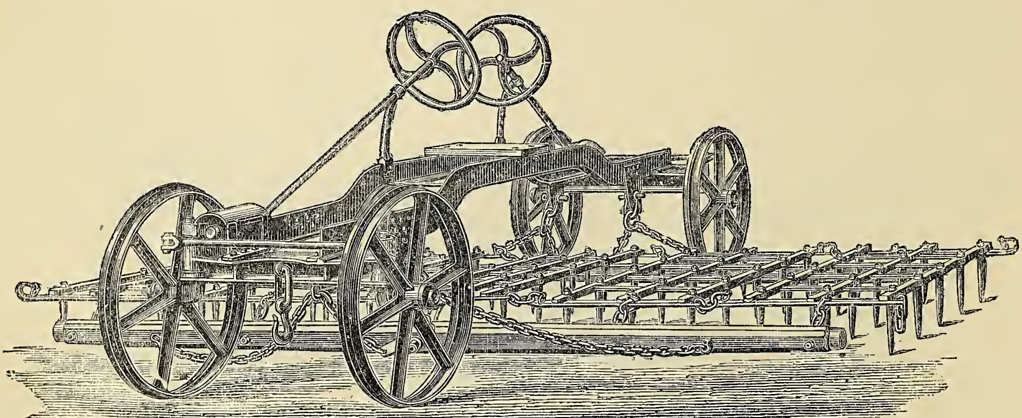


Fig. 16.—Steam Harrow.

The preceding remarks and illustrations will show how the progress of agriculture has been benefited by the introduction of machinery. As already stated, full details of these and other improvements will be entered into minutely under the head of Agriculture. In the following

illustration (Fig. 17), is represented an agricultural locomotive engine, used for the purpose of driving the machinery already described, with all other kinds employed now on the farm.

The engraving (Fig. 18) represents Burrell's improved patent agricultural locomotive and traction engine, showing an end view, with their patent winding-drum, &c.

Means of Transit.—The earlier means of transit and the conveyance of men and goods from one place to another, must necessarily have partaken of the rough and ready method. The use of animals, no doubt, was first adopted. We have an instance of this in the case of the sons of Jacob, who went down to Egypt to buy corn :—"And they laded their asses with the corn, and departed thence."—(Gen. xlii. 26). Of course the roads must have been of the rudest character, but this was not so much a matter of importance, as the animals had doubtless to subsist on the herbage they found as they travelled along, and time in those days, was not so

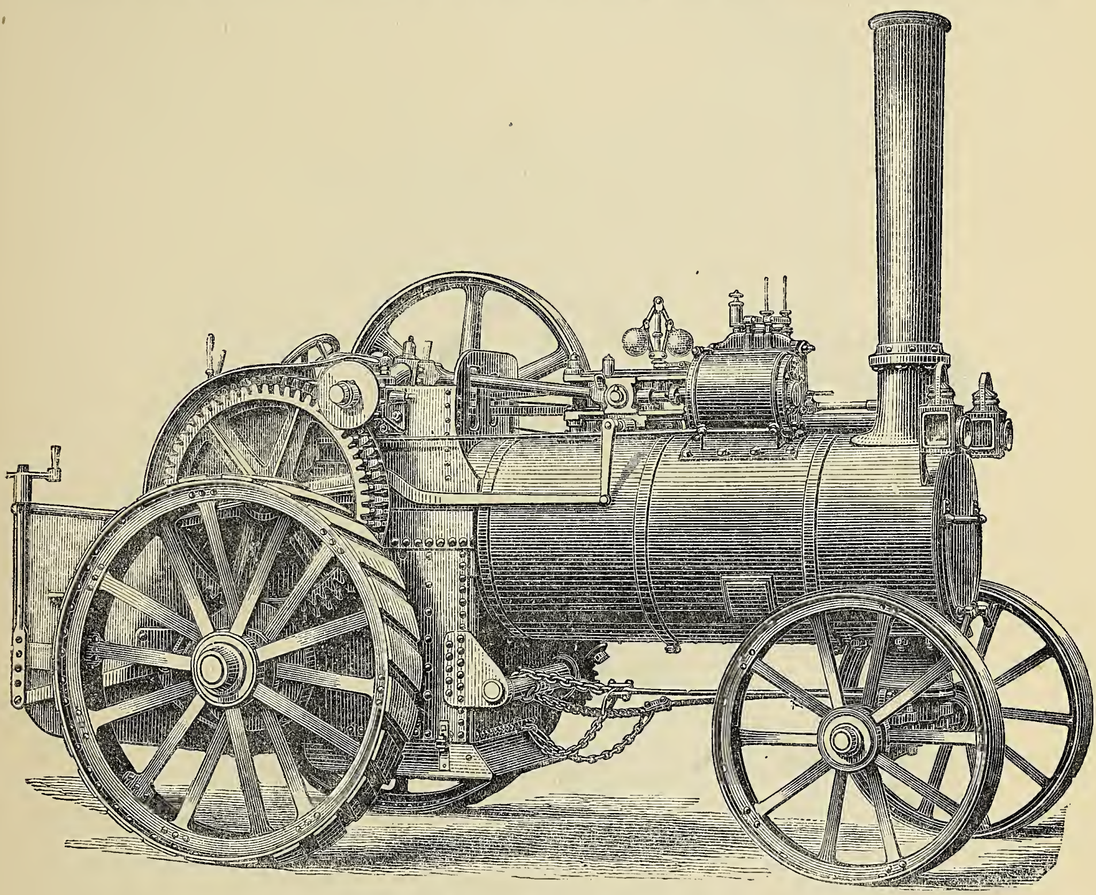


Fig. 17.—Agricultural Locomotive Engine.

much a matter of importance as we find it. Indeed, there are many countries at the present day in which travelling in its modern sense, is rather accidental than a custom. Not only have they made no progress in the construction of vehicles, but the training of animals to purposes of docile industry is almost unknown. A remarkable exception, however, is found in the case of the Esquimaux, whose reindeer and sleigh show an admirable adaptability to the necessities of the people and the exigencies of their climate, where conveyances fitted with wheels would be entirely useless. In Lapland, Sweden, Holland and some other countries, skating in winter time is resorted to for personal travelling. With the so-called "snow-skates," used in Lapland, where a snowy surface is more common than a smooth one, fifty miles per day is a common rate of travelling, and the great facility afforded by such a velocity

of movement led formerly in Norway to the establishment of a military corps called "skate-runners," or *Skielöbere.* Their power of harassing an enemy in the field was said to be very great, for they could pass in safety over snow much too soft for either cavalry or infantry; while their velocity of movement prevented any good aim being taken against them by artillery.

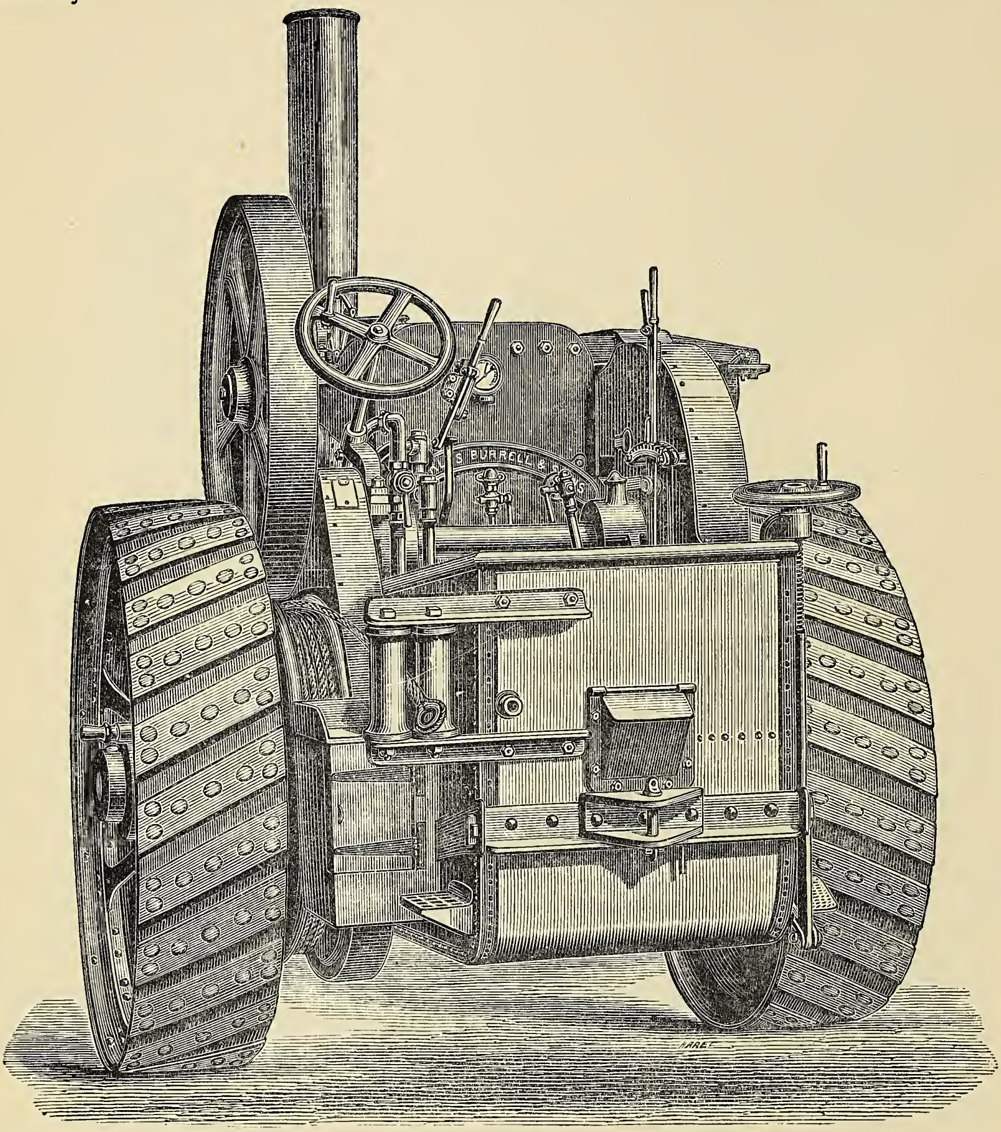


Fig. 18.—Traction and Agricultural Steam Engine, end view.

In the East the elephant was early used for the purpose of transit, the conveyance of goods, warlike stores, and in war. Indian, Persian, and Grecian history often refers to their use for the latter objects. Camel and dromedary travelling was early adopted in Persia, Arabia, and Africa. As beasts of burden, these creatures render to the inhabitants of hot sandy regions, an amount of service which no other known animal could supply. Hence, for ages they have been looked upon as invaluable. Their powers of enduring fatigue, hunger, and thirst; their strength in respect to carrying heavy burdens; their general docility and tractableness, all concur to give them a high stamp of value.

The use of the ox, as a beast of draught, and even saddled, has been described by many travellers in different parts of the world. In Southern Africa, and generally by African explorers, this animal is largely used as a beast of draught. Ox waggons are almost universally employed in and around Cape Colony. The use of the ass as a beast for draught, burden, and riding is very ancient, as already noticed, and the mule is still largely employed in Spain, Switzerland, and other modern countries. Dogs have been, and still are used as beasts of draught, one of the most remarkable instances of which may be seen in the sleigh-dogs of the Esquimaux, they being also largely employed in all the expeditions that have been taken by modern explorers of the Arctic regions.

We next turn to the more modern arrangements adopted in Europe, &c., but chiefly so far as their history is concerned, to those of our own country. The early use of wheel-carriages in England has been a matter of some antiquarian research. Riding on horses seems to have been first adopted by the better classes, and the saddle was generally preferred, although in the time of the Normans, the "horse litter" was much used, but chiefly for ladies. It was a kind of sedan, with double shafts having two horses, instead of two men to bear it. Stow says that coaches were not used in England, until the year 1555, when Walter Rippon made a coach for the Earl of Rutland. This differs slightly from the account which Taylor, the "Water-Poet" gives. He says that Queen Elizabeth "had been seven years a Queen, before she had any coach; since when they have increased with a mischief, and ruined all the best housekeeping to the undoing of the watermen, by the multitudes of hackney-coaches. But they never swarmed so much as they do now, till the year 1605, and then was the gunpowder treason hatched, and at that time did the coaches breed and multiply."

Stage-coaches, at whatever date they may have been introduced, did not acquire much importance until the reign of Charles II. But at that period the number had become so large that many tradesmen of London thought proper to petition the King and Privy Council against them; under the several pleas that these coaches injured the rents and profits of inns, lowered the value of farming produce, and inflicted other injuries. A counter memorial was presented by the coach owners, either denying or explaining away the several charges. Like other instances of the same kind, the opposition to the spread of a public good was fruitless, and the use of stage and hackney coaches gradually extended.

According to an Itinerary published in 1603, it appears, that at that time there were post-houses established on the great roads at intervals of about ten miles apart, for supplying horses to travellers who went on horseback. There were also carriers, it tells us, with "long covered waggons," which "carry passengers from city to city; but this kind of journeying is very tedious, for they must take waggon very early, and come very late to their inns; so that none but women and people of inferior condition travel in this sort. Coaches are not to be hired anywhere but at London; and although England is for the most part plain, or consisting of little pleasant hills, yet the ways far from London are so dirty that hired coachmen do not ordinarily take any long journeys." Another work, but of a more querulous kind, published in 1673, in the midst of a great mass of grumbling and discontent, gives a few facts worth noticing. "York, Chester, and Exeter stage-coaches, each of them with forty horses a piece, carry eighteen passengers a week from London to either of these places, and the same number in return from thence to London. There are also other coaches which, with four horses, and carrying six passengers, go daily to places within twenty and thirty miles of London, and others that go and return the same day from places within ten miles. There are stage-coaches that go to almost every town within twenty or twenty-five miles of London, wherein passengers are carried at such low rates that most persons in and about London, and in Middlesex, Kent, and Surrey, gentlemen, merchants, and other traders that have occasion to ride, do make use of, who, before these coaches did set up, kept a horse or two of their own, but now have given over keeping the same." Another passage gives us a little insight into the fares charged by stage-coaches at that time. "From London to Exeter, Chester, or York, you pay 40*s.* apiece in summer, and 45*s.* in winter, for your passage; and as much from those places back to London. Besides, in the journey they change coachmen four times, and there are few passengers but give 12*d.* to each coachman at the end of his stage; which comes to 8*s.* backward and forward, and at least 3*s.* comes to each passenger's share to pay for the coachmen's drink on the road; so that in the summer the passage backward and forward to either of these places costs £4 11*s.*, and in winter, £5 1*s.*; and this *only for eight days' riding in summer and twelve in the winter!*"

How would the writer have marvelled to be told of a train running from London to Leeds in four hours? As a means of mitigating the nuisance of which he complains, the "Lover of his Country" (for so the writer designates himself) suggests as follows:—"If some few stages were continued, to wit, one to every shire-town in England, to go once a-week backward and forward, and to go through with the same horses set forth with, and not travel above thirty miles a day in the summer and twenty-five in the winter, and to shift inns every journey, that so trade might be diffused, there would be sufficient to carry the sick and the lame, that they pretend cannot travel on horseback; and, being thus regulated, they would do little or no harm; especially if all be suppressed within forty or fifty miles of London, where they are no way necessary, and yet so highly destructive."

It would be tedious to trace the history of mail and stage coaches, and the so-called hackney carriages, to the date of the introduction of railways, but as a matter of historical interest, the following cut, Fig. 19, is given, representing coaches in use in the reign of Charles II.

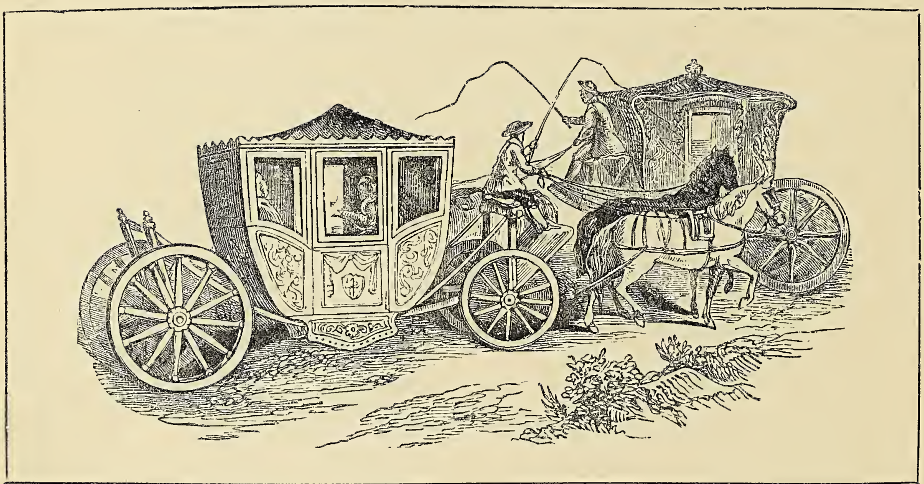


Fig. 19.—Coaches of the time of Charles II.

Omnibuses, like many other conveniences of life, owe their origin to the ingenuity of one who failed to reap an adequate reward. In July, 1829, a coach-proprietor named Shillibeer started in London the first omnibus that ever successfully plied in this country. Such carriages had long been common in Paris; but when, so far back as 1800, a similar vehicle was put upon the road in London, with four horses, it looked so exceedingly like a hearse, that people would not ride in it. The peculiar advantage of Shillibeer's carriage was its great capacity, which enabled him to accommodate from seventeen to twenty persons, at but little greater expenditure than what was required by the old stage-coaches to convey twelve or fourteen. This caused an important reduction in fares. Again, at least ten of the passengers were protected from bad weather; whilst, by the old system, not more than four, or at most six, could ride 'inside,' and that at nearly double the cost of outside places. Shillibeer made no difference in the charge; his omnibus was therefore much patronized. It ran between Greenwich and Charing-Cross, and was drawn with three horses abreast; but this was found not to answer, the middle horse being always severely distressed by the irregular stepping and perspiration of its neighbours. After some of the new vehicles began to run on the Paddington Road—which success between Greenwich and Westminister soon led to—only two horses were used, as now.

The development of the omnibus traffic, has been astonishing. At the present day nearly every town has its "busses" and these have been of recent years supplemented by the tramcar, a partial adaptation of the railway system of which we have next to speak.

We have no intention of tracing here the early history of railways, or the development of the locomotive engine, and our remarks, therefore, will refer to the Liverpool and Manchester line alone. As early as 1822 the merchants of Liverpool and Manchester felt how much business was interfered with by the slow means of transit between the two cities, and the construction of a railway was discussed, but it was, however, not until 1825 that application was made to Parliament for the necessary powers. We have now before us the photographic reproduction of the Parliamentary survey, entitled, "A plan and section of an intended railway or tramroad, from Liverpool to Manchester, in the County Palatine of Lancaster." This map has no date, but it is signed by Messrs. George and John Rennie, and it bears a statement that it was "surveyed under the direction of George and John Rennie Esqrs., F.F.R.S., civil engineers, by Charles Vignoles." The application of 1825 was unsuccessful, but it was renewed the following session, and with more fortunate results. Meanwhile, in 1825, the Stockton and Darlington line had been opened, and the success of this undertaking had, no doubt, a powerful effect in obtaining support for the Liverpool and Manchester Railway. It was at first proposed to use stationary engines and ropes for drawing the carriages, such as were some years ago employed on the London and Blackwall Railway; but eventually the use of locomotive engines was decided on.

In April, 1829, a premium of £500 was offered for the best engine, the following conditions being imposed: "(1) The engine must effectually consume its own smoke; this condition having been imposed by the Act authorising the construction of the Liverpool and Manchester Railway. (2) The engine if of six tons weight must be able to draw after it day by day twenty tons weight (including the tender and water tank), at ten miles per hour, with a pressure of steam in the boiler not exceeding fifty pounds to the square inch. (3) The boiler must have two safety valves, neither of which must be fastened down, and one of them must be completely out of the control of the engine-man. (4) The engine and boiler must be supported on springs, and rest on six wheels, the height of the whole not exceeding fifteen feet to the top of the chimney. (5) The engine with water, must not weigh more than six tons; but an engine of less weight would be preferred, on its drawing a proportionate load behind it; if of only four and a-half tons, then it might be put on only four wheels. The company to be at liberty to test the boiler, &c., by a pressure of 150 lbs. to the square inch. (6) A mercurial gauge must be affixed to the machine showing the steam pressure to above forty-five pounds to the square inch. (7) The engine must be delivered, complete and ready for trial, at the Liverpool end of the railway not later than the 1st of October, 1829. (8) The price of engine must not exceed £550." The engines sent in to compete for this prize were the "Rocket," of Mr. Robert Stephenson, the "Sanspareil," of Mr. Timothy Hackworth, the "Novelty," of Messrs. Braithwaite and Ericsson, and the "Perseverance," of Mr. Burstall; the last-mentioned engine was, however, found unfit for trial. The competitions commenced on October 8th, 1829, on a level piece of line one and a-half miles long, at Rainhill, near Liverpool, and they resulted, as is well known, in the award of the prize to the "Rocket," this engine taking a load of seventeen tons (which was pushed and hauled alternately) and attaining a mean speed during forty runs of 13·8 miles per hour.

The construction of the Liverpool and Manchester Railway naturally met with much opposition, but despite the sneers of scientific men and powerful opposition of interested parties, the directors of the railway persevered, and at last succeeded. They encountered unexpected difficulties, especially in laying the lines across Chat-Moss, a boggy district that swallowed up thousands of money. But the ingenuity of Stephenson and others overcame this and all other difficulties, and the day of opening at last arrived. We quote the following account of this event, as a matter of special historical interest at the present day, from the *Annual Register*, of 1830:—

"On Wednesday, September 15th, as early as seven o'clock, the people of Liverpool were seen flocking in crowds to the tunnel, in order to secure good places for a view of the procession. The whole line of road, for the distance of seven or eight miles out of Liverpool, was lined by dense crowds; and several stands, to which the public had been admitted at half-a-crown a head, were completely filled. Eight of the Company's locomotive engines were brought down to the mouth of the tunnel at about half-past nine. The Duke of Wellington arrived about ten o'clock, and was greeted with enthusiasm by the immense crowd.

"The procession left Liverpool at twenty minutes before eleven, drawn by eight locomotives, carrying the directors, visitors, and shareholders. On issuing from the smaller tunnel at

Liverpool, the 'Northumbrian' engine took the south or right-hand line of railway, and drew three carriages, the first containing the band, the second the Duke of Wellington and others, and the third the directors of the railway. The other seven engines proceeded along the north line. The total number of persons conveyed was stated to be 772. The procession did not proceed at a pace of more than fifteen or sixteen miles per hour. In the course of the journey the 'Northumbrian' accelerated or retarded its speed occasionally to give the duke an opportunity of inspecting the most remarkable parts of the work. On the arrival of the procession at Parkside, the carriages stopped to take a supply of water. Before starting from Liverpool the company were particularly requested not to leave the carriages, and the same caution was repeated in the printed directions describing the order of procession."

So far the above narrative supplies the bright side of the inauguration of the railway system. But, unfortunately, the event was accompanied by an inauguration of railway accidents. Mr. Huskisson, disregarding the instructions just alluded to, left his carriage at Parkside, where a stop was made for water; an engine, the "Rocket," was passing, and, overbalancing himself, his right leg came in contact with the wheel of the engine, by which he sustained such injuries as shortly afterwards caused his death. He was subsequently interred at Liverpool, a public funeral having been arranged in his honour.

At the present rate of railway travelling, it may be interesting to give the results of about a week's work in regard to the Manchester and Liverpool Railway. It appears that from Friday, the 17th, to Saturday, the 25th of September, that is, for the week after the line was opened, the number of passengers was 6,104, averaging 763 per day; the money received was £2,034 11*s*., or about £254 per day. This may appear trifling if taken in the light of the present receipts of the same railway; but, bearing in mind that previous to the opening of the line, there were only a few stage-coaches between Manchester and Liverpool, whose journey occupied about four hours, the statistics of the success of the new line were astonishing.

It is needless for us here to trace the gradual development of the railway system. At first prejudice stood much in the way of its progress, and the directors of each new line that opened had to so arrange matters that the old coaching system only gradually became a thing of the past. In the year 1830 some twenty or thirty mail and stage-coaches daily carried all the passengers from London over the area now embraced under the London and North-Western, Great Northern, and Midland systems. Goods sent from Manchester at that time would not be delivered in London under at least three and a-half to five days. A letter from Manchester or Liverpool was about eighteen hours at the quickest in transit, at the cost of about thirteen pence. On the other hand, constant stoppages for passengers, examination of tickets, which was incessant, change of carriages through want of through trains, and the divided interests of jealous companies, made railway travelling, at first, by no means pleasant. Comparing, in fact, our present railway system with that which was in existence in 1840, the improvements which we now enjoy, whether for passenger, mail, or goods traffic, are greater than were presented by the newly formed railway system compared with coaching some fifty years ago. We give a sketch of the original Manchester Station of the Liverpool and Manchester Railway. (Fig. 20.) Architecturally, this station possessed no special claims for attention, but those who know the present enormous station at Manchester, will regard the old terminus with interest as affording some measure of the growth of railway traffic which has taken place since 1830.

The early forms of the locomotive were of a very crude character. In the following engraving is an illustration of one constructed by Trevethick. In this the piston worked vertically in the cylinder, and the piston-rod was connected with a lever, whose lower end acted on the carriage (Fig. 21).

It need hardly to be pointed out that the locomotive of the present day presents a striking contrast to the one represented in Fig. 21. But those who remember the early history of the present type of locomotives, will not fail to perceive how astonishing has been the progress of mechanical industry during the last thirty or forty years. The early engines used on the London and Birmingham Railway did not weigh more than from four to six tons, and generally they had four wheels. Now a common weight of the locomotive is from thirty to forty tons, and they usually have never less than six, but occasionally eight wheels. The adhesion of these to the rails is incomparably greater, and consequently the modern locomotive can draw enormous loads at speeds varying from thirty to seventy miles per hour. The pressure of steam to the boilers has also been greatly increased, ranging now from 150 to 200 pounds per square inch,

instead of from about forty or fifty pounds formerly employed. The construction of locomotive engines has now become a special branch of mechanical engineering, and as such has attained an astonishing degree of perfection.

The science of civil engineering, of course, was the subject of great expansion, owing to the introduction of the railway system. Stephenson had enormous difficulties to contend with in the construction of the Liverpool and Manchester line. The London and Birmingham line also

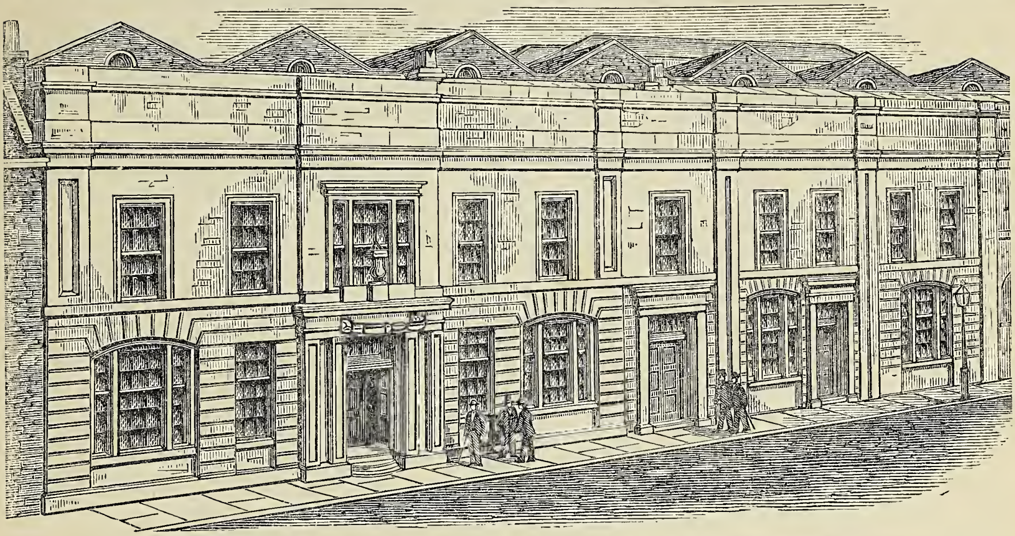


Fig. 20.—The old Manchester Station, Liverpool and Manchester Railway.

presented many and entirely unforeseen circumstances, which had to be provided for after their discovery. The tunnels on that line were difficult of construction, and, in some instances, all but ruinous to the contractors. Brunel, as engineer of the Great Western Railway, struck out a bold course, and did everything on the large scale. He adopted what was called the "broad gauge" of seven feet between the rails, instead of the narrow gauge, which has now become universal. At one time, owing to the variety of the gauges, great inconvenience was caused, not only to passengers, but also to the managers of the lines. From the same cause, the expense of engines, carriages, &c., was unnecessarily great, whereas, at the present day, owing to the uniformity of gauge, a person may travel without change of carriage, from the extreme south-west part of England to the last point of land in the north of Scotland.

Roads, bridges, &c., had to be modified to suit the new system. The old system of road-making was utterly inapplicable to the requirements of the railway, which has to convey within the same length and area, tons in weight, where hundredweights were formerly carried. A modern locomotive will weigh from thirty to forty times as much as the old stage-coach, hence, great care has to be taken in laying the foundation of the railroad, constructing its bridges, and other necessary works. Modern bridges, constructed for railways, have been made of great length in this and foreign countries, instances of which may be seen in many of our lines. Among the more recent constructions of this kind may be mentioned the bridge over the river Tay in Scotland. It, however, unfortunately was partly destroyed by a terrific gale of wind, not long after it was opened. In the engraving, on

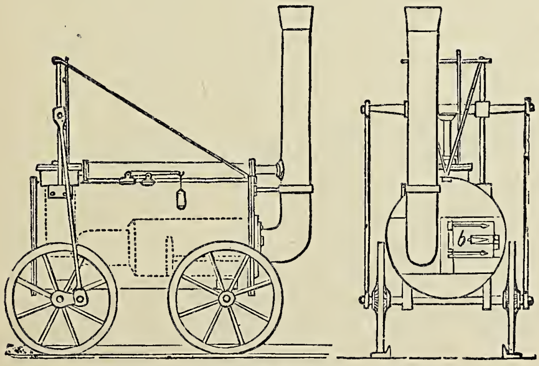


Fig. 21.—Trevethick's Locomotive, side and end view.

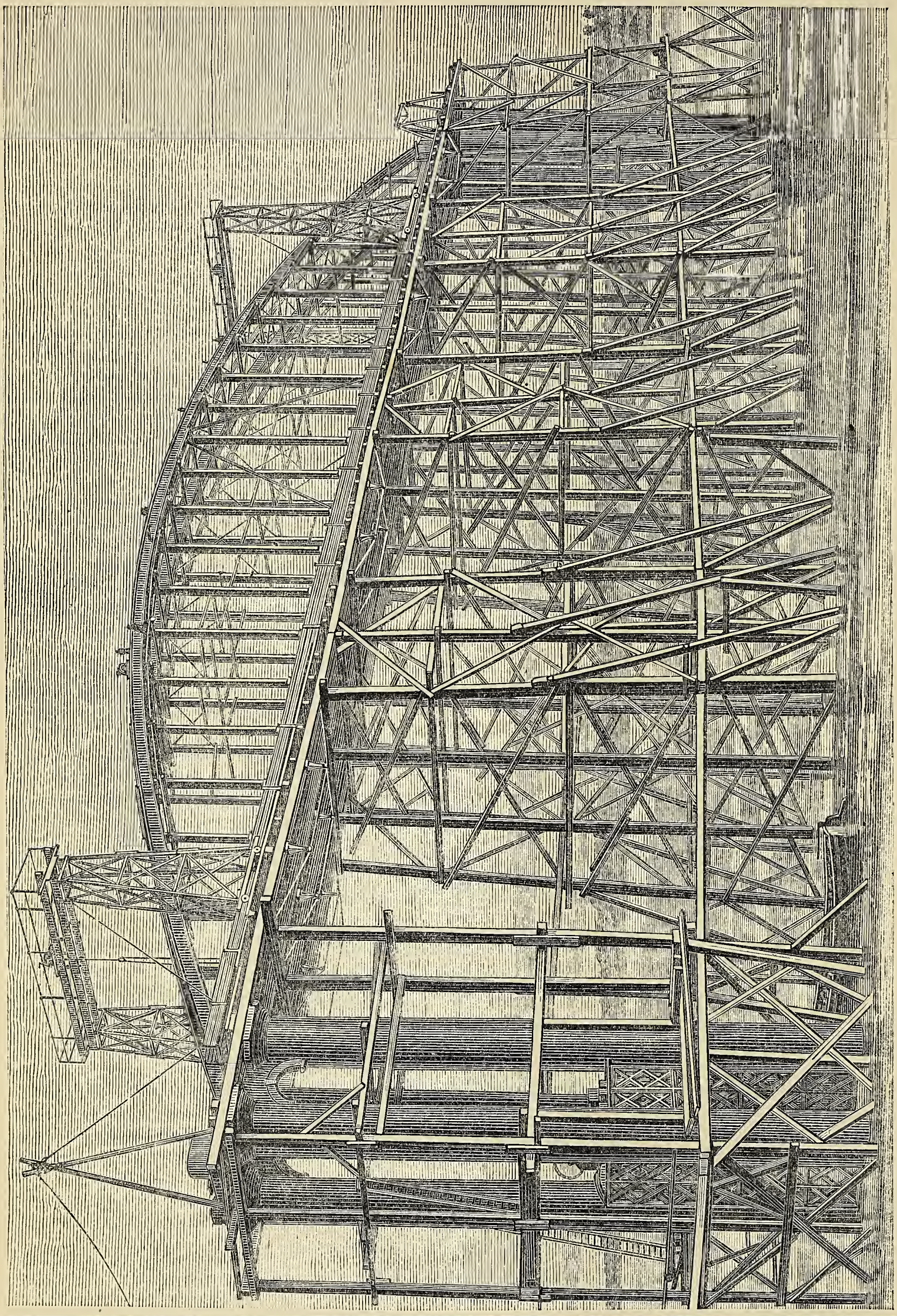


Fig. 22.—The Severn Railway Bridge.

page xxx, is a representation of the Severn Railway Bridge, which was opened for traffic in 1879. Its whole length is 4,162 feet, including twenty-two spans, one of which is shown in Fig. 22.

In the machine works, the railway system has produced astonishing revolutions. For the present, we must only notice a few of these instances. In tracing the early history of metallurgy the difficulties which then occurred in regard to fuel and imperfect machinery, were there pointed out. Iron, even in the malleable form, has, of course, to undergo numerous changes of shape to fit it for the construction of machinery. It has two especially valuable properties, namely, that of being beaten, drawn, bent, or otherwise shaped to any extent at a high temperature, into any desirable form, and also that of being capable of *welding*, that is, two pieces of iron at a white heat can be hammered together until they form one, in which no visible joint exists. It is in this latter property that the value of iron is so great in the construction of machinery,

The common blacksmith's forge is a rough illustration of the method of thus dealing with iron to convert it into useful forms. The early appearance of this instrument was of the crudest form. In the annexed engraving is a representation of an old smithy, copied from a curious illumination to a manuscript, with the extraordinary contortion of figure in which the Anglo-Saxon artists sometimes indulged. (See Fig. 23.) There seems to have been some plan, even in most ancient times, of keeping up a fierce heat by blowing, as adopted in adapting metals for manufacturing purposes; for many of the ancient Egyptian paintings show indications of this practice, which are valuable as historical reminders, however rude, and even ludicrous, they may be as pictures. One of these paintings is represented in Fig. 24 on the next page.

Fig. 23.—Smithy, as represented in an ancient MS.

Slow work this must have been for the artificers. Yet, despite all these difficulties, they succeeded in producing some excellent specimens of work. But in course of time, steam power was called in to replace the hand labour of the smith, in the use of the hammer. Hence the invention, by Nasmyth, of the steam-hammer, subsequently improved by Condie, and many other inventors, and it is now so needful, that nearly every process of the iron manufacture is preceded by the use of the steam-hammer.

Its construction is easily explained. Steam is introduced into a cylinder overhead, at a high pressure. Its admission is regulated by a stopcock. Inside the cylinder is a piston, which, being forced down by the steam, drives down the hammer on the object to be beaten, say a rod of white-hot iron. These hammers are made of every size, from those suitable for the smith's work, to others that are employed in forging the massive shafting used in machinery, for the driving the screws of the largest steam vessels, &c. In the following cut is a representation of one employed for ordinary smithy-work, and constructed by Messrs. B. and S. Massey, of Openshaw, near Manchester (Fig. 25). A represents the cylinder into which the steam passes from a boiler by the pipe B. The hammer is shown at C, acting on a piece of rod-iron by the workman at D.

These machines can be so easily and nicely regulated that the largest kind, capable of giving a force of many tons at each stroke, can be used to crack a small nut without smashing its kernel. Our illustration of one of the largest kinds appears in a folio plate.

We cannot here enter further into a discussion of the improvements which have of recent years been adopted by the mechanical engineer for converting iron into its various forms, such as bars, angles, plates, sheets, nailrods, hoops, &c. These will be dealt with in their proper place. Our present object is simply to bring to the mind of our readers some idea of what science has done for us in this branch of mechanical industry.

Textile Manufactures.—With the exception of those arts that are connected with the production of food, there are none of greater importance than those which furnish us with

clothing, and, curious indeed, are the varieties of this article presented to our notice. From the foot to the head, almost every possible variety of costume has been adopted, according to

Fig. 24.—Ancient Egyptian Forge or Bellows.

necessity, convenience, custom, or fashion. With respect to materials, almost all possible kinds have been employed. Most probably the wool of the sheep was the first used, then fibre, such as that of flax, &c., followed. Of course, the choice of material would much depend on the changes of climate, which would induce the employment of both flax and wool, the former for summer, and the latter for winter use. There is no doubt that the skins of animals were the earliest materials for warm clothing, as they now are among the Esquimaux, the Laplander, and other inhabitants of the Arctic, or Semi-Arctic regions. And in our own and other European countries, including, also, Canada, the United States, &c., the use of dressed furs is universal during winter, and forms a very important branch of industry, relating to the business of the Furrier. The records of our travellers and voyagers afford abundant evidence that the skins of animals preceded textile fibres as a material for dress; and the history of the early nations corroborates this opinion. The art of converting these skins into leather was very early known; for the outer coverings of the Tabernacle are said to have been made from rams' skins and the skins of badgers; and as these are spoken of as being dyed, some kind of tanning or dressing must have been carried on. Shoes, bottles, and girdles, too, are often alluded to as having been made of leather.

The nations of whose early history we have any authentic account, soon, however, acquired the art of weaving fibres into the form of cloth. The phrase "vestures of fine linen," used in Genesis, as applied to the dress of the superior officers of Pharaoh's court, shows that weaving of fibres into cloth was known at a very early period. All the allusions to woven textures as worn by the Israelites seem to afford proof that Egypt took precedence of Judæa, and of all other nations in that department of art. The linen manufactured in Egypt long maintained its superiority in foreign countries. It was called "fine linen," by way of pre-eminence, and formed a material part of the exports of that country.

It is quite evident that linen constituted a notable material for dress among the Israelites, and that there were different kinds appropriated to different purposes; for there are allusions in the Pentateuch to "fine linen," "fine trimmed linen," and "fine linen of woven work." It is known, also, that linen was worn by the Syrians and the Assyrians, as well as the Israelites and the Egyptians. Linen was more used than wool in those times; but the latter material was not neglected, for we find frequent allusions to its use. Heeren, in his learned *Historical Researches* concerning the Eastern nations, after speaking of the difficulties which lie in the determination of the question how far silk and cotton were known to the ancients, thus alludes to woollens and furs:—"The finest descriptions of wool, manufactured principally in Babylonia and the Phœnician States, were the production of many parts of Asia. Herodotus himself has given us a description of the Arabian sheep, distinguishing the two sorts of which the breed is

composed, that with a long, and that with a broad tail. In the mountains, also, of Northern India, the district of Belur, or the vicinity of Cashmere, were found then, as at present, large flocks of sheep, which constituted the wealth of the inhabitants ; and no one acquainted with ancient history needs to be reminded of the rich fleeces of the sheep of Asia Minor, particularly those in the territory of Miletus. The Milesian wool was accounted by the Greeks the finest of all, probably because they confounded with the native fleeces of Miletus the wool of Arabia and Central Asia exported from that city. There are also abundant proofs that another branch of trade, now of great importance, that of furs, not only existed in the times of which we are speaking, but had attained considerable importance. Supposing it to have been of less importance than it is at present, the cause was not so much from want of acquaintance with the fur countries as that the temperate climates enjoyed by the then civilised nations of the world

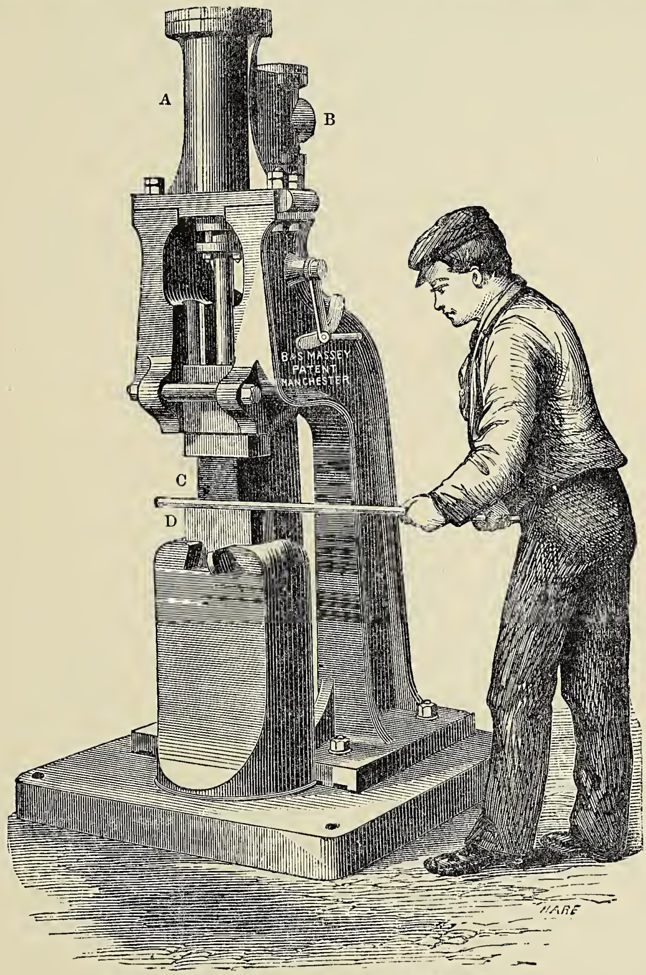


Fig. 25.—Massey's Steam-smithy Hammer.

rendered this article of dress unnecessary. The Grecian colonies to the north of the Euxine formed, however, an exception to this rule. They drew supplies of peltry, the skins of the otter and beaver, from the very interior of Russia, and possibly even from the shores of the Baltic, and easily disposed of them in the neighbouring country of Thrace, the inhabitants of which were principally clothed in furs. It may be observed that the Amazons are also occasionally represented in sculpture as thus habited, or rather (which is observable) loosely arrayed in furs. The use of them would appear to be in general a matter of luxury as well as necessity, even in warm climates, as it continues to be at present among the Turks. In his account of the army

of Xerxes, Herodotus enumerates several nations habited in the skins of animals; as, for instance, various tribes from the east and north-east of the Caspian Sea, the Utii, &c., as well as the inhahitants of the rugged mountainous tract on the south-east boundary of Great Bucharia, the Pactyes of Belur-land, and others."

Accustomed as we are in modern times to have every article of apparel prepared for us, from the production of the material to the making of the dress, such forms a striking contrast with the ancient history of textile manufactures. In early times the preparation of the materials for clothing was not as now, a separate branch of trade carried on for profit, so much as an employment for females in the domestic circle. The dressing of flax, the carding of wool, and the processes incident to spinning and weaving, were not considered unworthy of the attention of the high-born and wealthy. The matron of the family, generally superintended all such arrangements which were carried on under her roof. There are in the 31st Chapter of Proverbs many enumerations of the qualities of a good house-wife:—"She seeketh wool and flax, and worketh willing with her hands."—"She layeth her hands to the spindle, and her hands hold the distaff."—"She is not afraid of the snow for her household, for all her household are clothed with double garments."—"She maketh herself coverings of tapestry, her clothing is of fine linen and purple."—"She maketh fine linen and selleth it; and delivereth girdles to the merchants."

The system of domestic spinning and weaving, was carried on not only for the supply of the household with materials for dress, but also for making presents to guests, and for the sake of clothing the poor. An instance of the latter we find in the case of Dorcas mentioned in the New Testament. Even in our time these practices are not obsolete in our own country, for in Wales and the North of Scotland the production of hand-made hosiery, and other articles made from wool, is common.

But what a contrast does this present to the progress and general position of our textile manufactures of the present day! and for the sake of comparison we may briefly glance at the manufacturing districts of our own country.

Let us draw an imaginary line from Liverpool to Hull, across the country from west to east, and see what there presents itself. We shall find that almost the entire of the industrial arrangements, throughout a wide belt of country on either side of that line, have relation directly or indirectly to the production of clothing. The Liverpool merchants, with their docks and ships, though carrying on a vast trade in other departments, owe their wonderful commercial position mainly to the cotton trade; they being, almost exclusively, the media of interchange between the cotton-growers of foreign countries and the cotton-manufacturers of England; and being also, when the crude fibres have been worked up into cloth for garments, one of the chief means of dispersing these goods over the whole globe. Proceeding thence eastward towards Manchester, what do we see? The roads, the canals, the railways, all owe their existence, to so large a degree, to cotton, that we may almost deem them part and parcel of the great system. The Liverpool and Manchester Railway would probably not have been made but for the immense traffic in cotton—raw, from west to east, and in piece-goods and yarn, from east to west—established between Manchester and Liverpool. Then, in the circle of twenty miles' diameter, having Manchester in its centre, how undeniable is the fact that the production of clothing is the very life-blood of the district! The cotton factories, with their hundreds of thousands of workpeople, are only part of the system: there must be looms, carding-engines, spinning-machines, and all the countless machinery employed directly in the manufacture, and these must have artisans to make them: there must be bleaching, and dyeing and printing works, to impart a finish to that which leaves the loom in a rough state, and these in like manner must have the aid of machines calling forth the best talent of machinists: there must be steam-engines by hundreds, to give the moving power which sets all this mighty system in action; there must be builders and architects to plan and construct the vast edifices wherein these operations are carried on. Then how endless are the ramifications which spring from the main system itself! The transit from place to place gives activity, and a means of support, to carriers, canal and railway proprietors; cart, waggon, boat builders, &c. The large undertakings of the manufacturers call for the services of bankers, agents, brokers, engineers, solicitors, clerks, and others whose services are rather professional than mechanical; while the emolument earned by them, and the wages earned by workmen, give rise to a demand for the daily necessaries of life sufficient to maintain thousands of shopkeepers and dealers, both

wholesale and retail: and it is in this way that we find how the population of such a district forms an endless chain among them. It is true that, making an analysis in this way, it might be possible to show that a pin, a button, a book, or any other article, when its manufacturing history is traced, gives support to a large number of persons; but it is equally easy to see that, in the manufacturing districts, the mainspring which gives efficiency to all the links of the chain is the production of clothing.

When we leave the Lancashire and Cheshire district, and pass eastward to Yorkshire, we find that clothing is equally the staple on which the wealth and importance of the district depends. The wool-staplers of London, and the graziers of the midland counties, carry on a large department of trade in supplying Yorkshire with the crude materials from which cloth is to be made; while the merchants and ship-owners of Hull bring over wool from Germany, and flax from Holland, and hemp from Russia, to aid in this supply of materials. Then, the manufacturers of Yorkshire being thus supplied, they proceed to work up the diversified kinds of cloth with which we are all familiar; Halifax and Bradford take one department, Huddersfield another, Dewsbury another, while Leeds takes precedence both for the woollen and for the flax departments; and each of these towns forms a nucleus for a very hive of clothing villages. Then come all the train of subsidiary operations, arising out of the staple manufacture; from the making of a gigantic steam-engine for a flax-mill, to the serving of the little daily wants of a workman from a retail shop. The hungry mouths of the Yorkshire clothiers give prosperity to the town of Wakefield, which is the greatest corn-selling town in the North of England; and the agricultural population, for a wide range of country north and south of the clothing district, look to these clothiers as their best customers.

Next we may notice Scotland with Glasgow as its commercial centre. Of late years this city has vied with Manchester in respect to cotton, wool, silk and other manufactures, dyeing, calico printing, &c. The most powerful machinery employed for motive power, is here made, with shipbuilding, and other analogous trades. In its vicinity are enormous beds of coal, iron ore and limestone—and, as at Coatbridge and other places in its neighbourhood, every form of iron, steel, and other machinery is made.

Passing easterly to Falkirk, we again find the iron manufacture prominent, but on arriving near the east coast of Scotland we enter another phase of manufacturing industry. Flax, hemp, jute, and other fibres are here converted into fine linen or to sack-cloth. Next in importance we may mention Paisley as noted for its shawls, and Kilmarnock for carpets, &c.

Among manufactures of minor importance it may be noticed that at Norwich, the bombazine and crape manufacture is larger than any other; at Northampton, the manufacture of shoes and boots takes the lead; at Newcastle-under-Lyne, the manufacture of hats is the staple; at Leicester and Loughborough, and a large number of neighbouring villages, the production of worsted hosiery and gloves is almost exclusively the source of occupation and support; at Nottingham, cotton hosiery and bobbin-net are decidedly the staple of the town; at Derby and Macclesfield, at Congleton and Leek, silk takes the lead before all other objects of attention; in a large number of towns in the counties of Cambridge, Huntingdon, Bedford, and Buckingham, the making of lace, and of plaited straw for bonnets, is, after agriculture, by far the most important occupation of the people; in a large and important part of the West of England, the making of woollen goods is the chief branch of industry.

When we come to the metropolis, we find that the industrial arrangements relating to clothing apply rather to the making of garments from the woven and otherwise prepared materials, than in the manufacture of those materials themselves; and to the trading consequent on the actual sale of the garments to the wearers. But even here we find that whole districts derive their importance from clothing. Bermondsey, for example, is an extremely busy manufacturing spot, the wealth and ingenuity of whose inhabitants depend mainly on the production of hats, leather for boots, shoes, and gloves, and the collecting and sale of wool for the clothing districts. Spitalfields and Bethnal Green, again, depend more on the trade of silk-weaving than any other employment.

To follow out this matter to its fullest extent is, of course, impossible here; but sufficient has perhaps been said to show how enormously the subject of clothing absorbs the attention of the people of this country. The ships that bring over raw materials of manufacture; the workmen who build those ships; the machinists who give the means of working, and the men who do the work; the forming of garments from the prepared materials, and the sale of the

garments so formed; the transit from one part of the country to another, and the shipment to foreign countries; together with the commercial, the financial, the professional, and the legislative arrangements arising immediately from these employments—form a whole which has no parallel, except as relates to the article of food; and even this exception only applies under certain points of view.

Having thus given a general idea of the classes of textile manufactures and their localities in this country, we next notice briefly some specialities of each, dealing with cotton, sheep's wool, flax, silk, &c.

It is almost needless to state that the application of steam-power to our textile manufactures has placed us in a position to command the trade of nearly the whole world. A comparison between the simple and stationary arrangements of the Hindoos, and the mighty energies of the English system, developes very notable results. So wonderfully perfect has our machinery become, and so great the skill displayed in every part of the manufacture, that the Lancashire manufacturers can pay for the importation of the raw cotton, for the process of manufacture, and for the expense of shipment to foreign parts, and yet undersell the Hindoos, who spin for three farthings a day!

Dr. Aikin, in his *History of Manchester*, separates the manufacturing system into four periods or epochs: the first, anterior to about the year 1690; the second, from thence to about 1730; the third from the year just named to Arkwright's time; and the fourth, subsequent thereto. During the first period, the manufacturers worked hard for a living, without accumulating any capital; and Aikin supposes there were few or none of them who possessed so much as three or four thousand pounds. During the second period, the manufacturers began to acquire small fortunes, but worked as hard and lived in as plain a manner as before, increasing their fortunes as well by economy as by moderate gains. They began to build modern brick houses, in place of those of wood and plaster; and they had dealings with wholesale firms in London, Bristol, Norwich, Newcastle, Chester, &c. "An eminent manufacturer of that age used to be in his warehouse before six in the morning, accompanied by his children and apprentices. At seven they all came in to breakfast, which consisted of one large dish of oatmeal-porridge, made of oatmeal, water, and a little salt, boiled thick, and poured into a dish; at the side was a pan or basin of milk, and the master and the apprentices, each with a wooden spoon in his hand, without loss of time dipped into the same dish, and thence into the milk-pan; and as soon as it was finished, they all returned to their work. In George I.'s reign, many country gentlemen began to send their sons as apprentices to the Manchester manufacturers."

During the third of these four periods, the manufacturers greatly extended the mode of conducting their dealings with the merchants. Before that time the chapmen or dealers used to keep gangs of pack-horses, and to drive them to the principal towns with goods in packs, which they opened and sold to shopkeepers, depositing the unsold goods in small stores at the inns, and taking back sheep's wool to the manufacturing district. By degrees, however, turnpike-roads were improved; waggons instead of pack-horses were laden; and the chapmen only rode out for orders, carrying with them patterns in their bags. In the second period, country districts were supplied from the five or six large towns which received goods direct from Manchester, each serving as a centre to the surrounding country; but now the manufacturers began to send their riders to every part of the kingdom, soliciting orders. The fourth period or epoch was consequent on the introduction of machinery into the manufacture. The trade became so large, that manufacturers in commercial towns went to reside in London or on the Continent; foreigners and London merchants sent agents to reside permanently at Manchester; agents, factors, and brokers were established, some at Liverpool and some at Manchester, to manage the transactions between the merchants of the one town and the manufacturers of the other, both in respect to the raw cotton and the manufactured goods; all the manufacturers around Manchester agreed to make that town their mart, and to appoint certain days of the week as "market-days" with each other, usually Tuesdays; and Manchester became, what it has ever since continued, one of the wealthiest towns of the empire.

Throughout three of these four periods the cotton manufacture was not strictly consistent with its name; for the "warp" or long threads of fustians, and other varieties of cotton goods, were made of linen, no mode being then known of making these threads strong enough of cotton. It was not until Arkwright's spinning-frame (Fig. 26) came into use that cotton-warps were made

fitted for such purposes. While this mixture of cotton and linen continued, the mode of manufacture partook much of the domestic system observable in India. The weavers lived in country spots, where they could follow gardening alternately with weaving. The cotton employed for the "weft" or cross-threads, was picked and cleaned by his younger children, carded and spun by his wife and eldest daughters, and woven by himself and his sons. As a good weaver could work up as much yarn as three efficient spinners could spin, the weaver had often to go from house to house, buying yarn wherever he could get it. The manufacturers of Bolton or of Manchester used to give out the linen-warp to the weaver, and leave him to provide the cotton-weft, and to weave the two into cloth; and, by the terms of the agreement, he incurred a penalty if the woven cloth was not returned by a certain day. Mr. Guest says that a weaver was often under the necessity of trudging three or four miles in a morning, and visiting many spinners before he could collect weft enough to keep his loom going during the rest of the day; and such was the competition which he met with from other persons having a similar errand, that he frequently had to fee and make presents to the spinners to allow him to be the purchaser. In short, the weavers were quite at the mercy of the spinners; and would, probably, have continued so but for the invention of Arkwright.

This extraordinary man—whose descendant, in an intervening period of only about seventy years, became nearly, if not quite, the wealthiest man in Europe—was the greatest among a small number who brought the cotton-manufacture to high perfection. Arkwright, Strutt, Crompton, Hargreaves, Kay, and a few others, mostly of humble origin, all contributed to this important work. Arkwright was born at Preston in 1732. He was brought up as a barber, which occupation he carried on at Bolton till about the year 1760. His first effort in mechanics was an attempt to discover perpetual motion—an abortive project, which has occupied so many persons in the earlier season of their career in mechanical studies. Observing the great scarcity in the supply of cotton-yarn for weaving, owing to the slow method of manufacturing it, Arkwright turned his attention to the matter, with the view of devising some mode of remedying the evil. In the course of his inquiries after some person qualified to assist him in making the movements of his first projected machine, Arkwright became acquainted with a clockmaker named Kay, with whose aid he carried out many of his ideas. In 1767 he gave himself up wholly to inventions connected with the cotton manufacture; but he was so poor that he could not decently appear at an election for Preston, until the person for whom he voted had given him a suit of clothes! Shortly after this, Arkwright went to Nottingham, where he fortunately met with encouragement from Mr. Strutt, who had made some improvements in the stocking-frame. Strutt had been a farmer, and, like Arkwright, had got into a different line of occupation from the force of mechanical genius. A patent was taken out for Arkwright's invention, Strutt finding the capital; and factories were established for "roller-spinning" on his method. The first mill erected was at Nottingham, and worked by horse-power; but in 1771 another was built at Cromford, near Matlock, in Derbyshire, in which the machines were worked by water-power. It was from this circumstance that the machine employed by Arkwright was for a long time called a "water-frame," and the yarn spun by it "water-twist." This was the foundation of Arkwright's prosperity. He had to contend against numerous infringements of his patents; but he surmounted all difficulties by his unconquerable perseverance; he invented

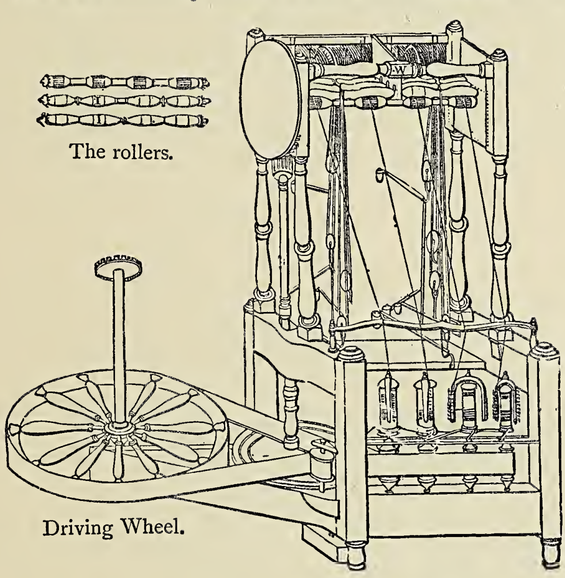


Fig. 26.—Arkwright's Original Spinning-Frame.

machines applicable to almost every part of the manufacture, and became a partner in a large number of factories in different places. He was, in fact, the father of the factory system, and had to devise arrangements necessary for the management of a number of persons in one place. By the year 1792, when he died, he had amassed a fortune of half a million sterling, and had opened a field of industry to which a large number of manufacturers directed their attention.

A few years before Arkwright began his career, James Hargreaves, a poor weaver of Blackburn, made an improvement in the common spinning-wheel, whereby it became much more effective than before. He had a large family to support by his earnings, and was in very straitened circumstances. It is said, that happening to observe one day a spinning-wheel over-turned upon the floor, and that the wheel and spindle continued to revolve, he was led to consider what would be the effect of placing the spindle perpendicularly instead of horizontally. He devised a mode of arranging several spindles in a row, so that they might all be made to revolve by the turning of a single wheel and thereby to spin several threads at once. His new machine he called (or it was soon called by others) a "spinning-jenny;" and he kept his invention a secret for some time, using it only to make weft for his own loom. But his wife, having more vanity than prudence, talked of her husband's ingenuity to some of her neighbours; and the neighbouring spinners, becoming alarmed lest their trade should be injured by the new machine, broke into Hargreaves' house, destroyed the machine, and forced him to leave the place. He went to Nottingham, where he entered into partnership with another individual, and took out a patent for his invention; some flaw in the patent prevented him from reaping all the benefit from his ingenuity which he deserved; but the spinning-jenny became extensively used for making weft-yarn, in the same way as Arkwright's afterwards did for making warp-yarn. (See Fig. 27.)

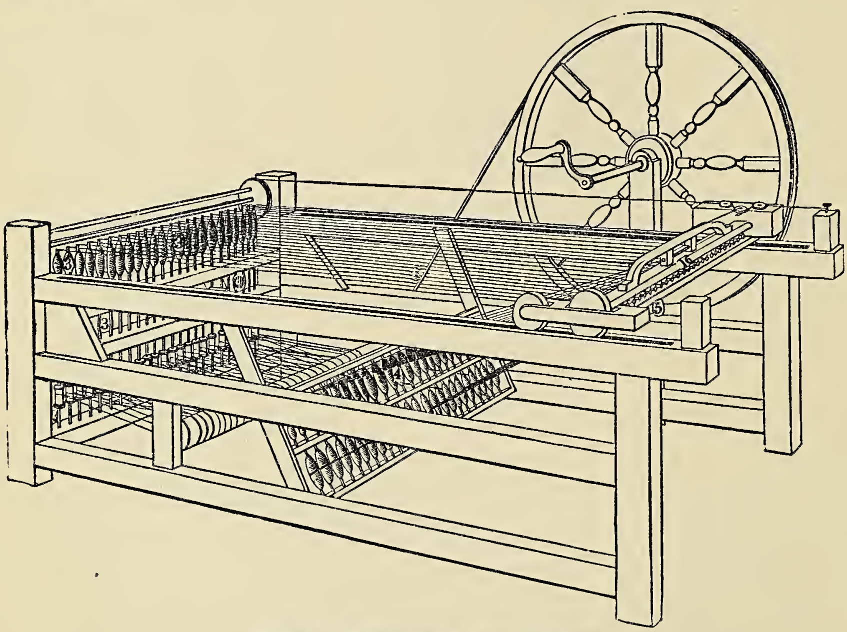


Fig. 27.—Hargreaves' Spinning-jenny.

Samuel Crompton was another of these benefactors to the cotton manufacture; and one, too, like the others, who had to suffer no small share of annoyance for his ingenuity. Crompton was a farmer's son, in a village of Lancashire, and was employed when young as a weaver. At the age of sixteen he learned to spin upon one of Hargreaves' "spinning-jennies," then recently brought into use. Being dissatisfied with the quality of the yarn he produced, he began to consider how he might alter and improve the machine. He devoted five years to the attempt, and at length produced that modification of the machine which has been called the "spinning-mule," and which was the foundation of the finer kinds of cotton manufacture in

this country, such as muslins. Like Hargreaves, he wished to keep his invention to himself, and to make yarn from it with his own hands; but as he got a better price for his yarn than other people did, his neighbours suspected that he had some new kind of machine. They came from all the surrounding districts to try to steal a glimpse of his apparatus and mode of proceeding, and when he worked in his garret they procured ladders, and looked in at his window. At length, tired out with this inquisitiveness, and not having the means of securing the invention to himself, he disclosed his secret to about fifty persons, who agreed to give him a guinea a-piece for it. The method thus became known generally, and was soon practised extensively. Crompton, about the beginning of the present century, had a sum of five hundred pounds presented to him by some gentlemen of Manchester; and ten years afterwards Parliament gave him a reward of five thousand pounds, as an acknowledgement of the extensive service which his machine had rendered. A statue of Crompton has been erected to his memory in Bolton, and forms a deservedly prominent object in the main street of that town.

In a national point of view cotton is the chief characteristic of our textile manufactures. France is similarly distinguished by its silk industries, although in every civilised country cotton, wool, silk, flax, &c., are the subjects of manufacture.

Cotton, as a raw material, is derived from numerous sources. Its cultivation and manufacture have been long known, although frequently, by old writers, it is confounded with flax. It cannot be safely cultivated in latitudes north or south of 35° from the equator, although such limits are more climacteric than real.

Many species of the plants are cultivated; and we may refer our readers to the Botanic Gardens at Kew, for several specimens there cultivated as objects of curiosity. Personally we must own to having never seen any plant in full bloom in this country—at least, in the perfection that it is seen in its native places. In such countries it presents a most pleasing appearance at the time of flowering, and one with which we have no analogue in any plants of temperate climes.

Chiefly four species of the plant are cultivated for commercial purposes. The *Gossypium herbaceum* has the shortest staple; that is, each individual fibre is short—say from half to three-quarters of an inch in length. It forms the Surat and Madras cottons of the importer. From our own experience we have generally found it of a yellowish, almost at times varying to a kind of brownish tint; of a rough feel to the hands and face; spongy, elastic, and after removal from the bale, rapidly increasing in bulk. The quality of cotton grown in the East Indies greatly varies, as is frequently verified at a pecuniary cost. There is no doubt that, as facilities of carriage increase, and as a better system of cleaning is adopted, the quality of the article will improve. East India cotton, however, so far as we have seen it, has the same evil quality as East India sheep's wool. It is of short staple, quickly breaks, takes dye badly, and bleaches worse; the two latter qualities alone being common to both articles.

During the American civil war of 1860—'64, this class of cotton was largely imported, simply because all other kinds were scarce. Its use necessitates an alteration of the *drawing* part of the machinery, because of the short nature of the staple. There is little doubt but that for the occurrence we have named, as for the time involving the peace of one of the mightiest and most prosperous nations of the world, East India cotton would have remained in its previous position—that of an inferior article.

Japan and China might afford an enormous quantity of the raw material for this country; but, for various reasons, political, national, and social, our import from those countries has hitherto been of a most limited character. As a rule, an abundant supply of any commodity greatly depends on facilities of carriage; but China and Japan are so thickly populated, that the internal demand for such an article as raw cotton, most likely prevents its export in any large quantity. Much of the value of any raw material depends on the facility with which it can be "worked up"—that is, its conversion into articles of economic use. Cotton presents the greatest facilities for this purpose; and hence, in places where it is naturalised, there is a tendency to retain, for home consumption, that which, if exported, would be of the highest value to us.

Many parts of Arabia are doubtless suitable for the growth of cotton, especially on the coasts of the Red Sea and Persian Gulf; but the production is very trifling, if it at all reaches this country. Egypt largely contributed to us during the "cotton famine" produced by the American civil war; and the staple—that is, the length and strength of the fibre—is mostly of

good quality. We have seen much cotton from Asia Minor; but, generally speaking, have found the article quite unfit for dyeing: it bleaches pretty well; but is most suited for making wicks for candles.

The southern portion of Africa, including Natal, &c., has produced some good varieties of cotton; and, as far as can be now seen, the production of our South African colonies will become of great importance in the lapse of time. Algiers, the most important of the French colonies, seems likely to produce much good cotton, if encouragement be given to the employment of capital. Our colonies in New South Wales, Australia, and Queensland have become a source, to a moderate extent, of the raw material, and the Feejce Islands have produced some excellent cotton of the Sea Island type.

But various parts of continental America must be considered as the most important cotton-producing of all countries in the world. All conditions essential to the growth and cultivation of the plant are there more fully existent than in any other part of the globe. We can scarcely find any other region in which the conditions of heat and moisture are so nicely balanced, together with a constant access, in many cases, of sea-air—an essential requisite for the production of the best kinds of good stapled cotton. South of the Gulf of Mexico, Brazil is the most noted of cotton countries, and there the variety, *Gossypium peruvianum*, is mostly cultivated. It almost equals the celebrated long-stapled Sea Island cotton. The colour is a rich creamy, or slightly brown white; this class takes dye well (for cotton), and also bleaches tolerably; although, from the presence of the sesquioxide of iron, or some resinous matter (we speak on guess, rather than fact), a slight yellow tint remains after the bleaching process is completed, independent of the usual addition of "blue."

In the United States of America—the chief cotton-supplying nation of the world, the species of the cotton plant called *Gossypium barbadense* is mostly cultivated (See Fig. 28); and hence, from its varieties, the American cotton, and that highly-esteemed sort called "Sea Island," used in spinning "fine numbers." It has a rich silky feel, or one soft to the touch, and entirely free from the harshness that East India cotton presents to the hand. It has a light colour—almost, if not occasionally, quite white, and receives dyes, or bleaches better than any other kind. Hence, arose its extensive use in our manufacturing districts, and those of the continent.

Fig. 28.—*Gossypium barbadense*—The Cotton Plant of the United States.

The Sea Island variety is that most esteemed of all kinds of cotton. Its chief place of production is on the sea-coasts of Florida and Georgia, in the south of the United States, where the saline matter, carried inland by the atmosphere, greatly promotes its growth, both in quality and quantity. In such districts its staple is long; whilst more inland the fibre becomes much shorter, and gradually degenerates into the ordinary kind previously described.

There are numerous other varieties, and, perhaps, species of cotton, grown in other parts of the world; but we have mentioned those of chief importance. The nature of the "wool" varies according to the climate, proximity to the sea, and other conditions, in respect to its cultivation generally. The following cut (Fig. 29), illustrates the leaf, flower, and pod of the Sea Island, or long-stapled cotton of Georgia.

The individual fibres vary in diameter, as well as length, according to the quality and variety. The Sea Island (Fig. 30) has an average diameter of about $\frac{1}{2000}$th of an inch, while

that of Surat, in the East Indies, is sometimes so coarse as $\frac{1}{500}$th of an inch. The edges and points of the fibre are generally the thinnest. A certain amount of friction is exercised between each, on a number being drawn out in parallel lines, either between the thumb and finger, or in the carding engine. The constitution seems to be that of a long riband-like tube, of little strength individually, but, collectively, as when spun, capable of sustaining much tensile force.

Fig. 29.—The Sea Island Cotton Plant.

By the operation of spinning, these tubes become flattened and stretched, and are thus changed still further into the riband form just described. Joints are rarely observed in cotton fibres; whilst they are common in those of flax. In the following cut (Fig. 31), a comparative view of the fibres of flax, cotton, wool, and silk are given.

Chemically speaking, we may consider cotton to consist of cellulose, or woody matter. By the long-continued action of sulphuric acids, it is converted into grape sugar; by concentrated nitric and sulphuric acids, it is converted into gun-cotton, a well-known explosive substance, substituted for gunpowder.

If there were no other reason, the physical character of cotton would be sufficient to account for the difficulty that is experienced in causing it to take colours permanently, for dyes become so in proportion as they can be introduced *into*, and not upon the fibres of textile substances. But there are evidently other reasons, of a chemical nature; for, by means of animal, or tannin matter, we can, as we shall hereafter see, succeed in producing such a change in the fibre as will enable it to take dyes almost as well as wool or silk, and as permanently, under certain circumstances.

In respect to bleaching, we have already mentioned that cotton, from different sources, varies greatly in this respect; and, so far as our own experience goes, we ascribe any fault, in this respect, to the presence of iron in the state of sesquioxide. Some years ago we made numerous experiments on every variety of cotton at that time imported into this country, and arrived at the conclusion just stated. For the same reason, it is very difficult, without great care, to bleach certain kinds of flax, hemp, and jute, by means of chloride of lime; a permanent yellowish-brown, or "jean" colour, being produced.

As the chemical processes to which cotton is subjected in dyeing, &c., are, to some extent, affected by the mechanical operations of spinning and weaving, which tend to render the fibres rigid, and, as already stated, of a flatter, or more riband form than they are naturally, it may not be out of place if we here give a general outline of the processes that are followed in converting the raw material into yarn or fabrics.

The cleaning of cotton immediately after it has been picked from the "field" is a matter of considerable importance; for the little specks that are often seen in the bleached and the dyed article, mostly arise from portions of the pod-case, that bleach "lumpy," and exhibit equal defects, for the same reasons, in dyeing. It is somewhat strange—at least, so far as we have seen—that, *after* bleaching, these specks present all the appearance of cotton fibre; and, in every experiment we have tried, the same result has been evidenced. Many of our readers practically engaged in the manufacture of cotton, may find advantage in bearing this fact in mind.

Cotton is imported, in almost every case, into this country in the form of bales, in which the material has been powerfully compressed by hydraulic pressure. The effect of

Fig. 30.

this is to economise the cost of carriage ; for, of course, such goods are paid for by bulk, and not by weight. We have found that East India cotton, thus packed, if opened out *by hand,* will gain, by absorption of moisture, from four to seven per cent in a very short time ; and if so opened, the loss in the subsequent operations of carding, spinning, &c., is greatly diminished. Precisely the same result arises with East India sheep wools. It is likely, therefore, that the extreme heat of the climate where it was produced, must dry it to an extent inconsistent with its economical working in this country. On one occasion we permitted a number of children to play amongst a large quantity of cotton thus thrown out of the bale, and found, not only that it carded and spun better, but that in dyeing it more readily took colour. The reason is obvious ; for the fibre thus became less rigid, less brittle, and, consequently, more open and elastic.

The first operation in the cotton manufacture in which machinery is employed, is that of willowing, by which the fibres are fully parted, and the mass rendered fleecy and open. The next step is that of arranging each fibre parallel, which is effected by carding. In this operation the cotton is passed over cylinders coated with fine teeth made of steel wire, that, revolving rapidly, tend to separate and arrange the individual fibres side by side. In this operation a considerable amount of "waste" is made, which, however, is in part used up for making low-priced yarns and goods, and also in the manufacture of waddings for filling muffs, boas, ladies' dresses, &c., &c.

The intermediate steps between the production of cotton, carded and spun, we need not here detail as that will become a subject of subsequent discussion ; suffice it to say, that by drawing and twisting the fibre, what is called yarn, or a single thread is produced. This may

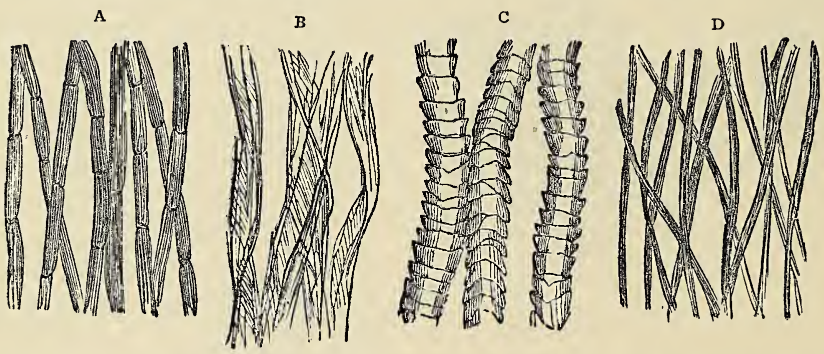


Fig. 31.—A represents fibres of flax ; B, those of cotton ; C, those of wool ; and D illustrates filaments of silk as taken from the cocoon.

be either hard or soft twisted, according to the previous methods of drawing and spinning. Both kinds of this yarn are required for the purpose of weaving, one forming the warp, and the other the weft of calico, or cotton cloth.

We have already stated that these processes have a tendency to prevent the cotton fibre from quickly taking a dye. It must be remembered, however, that when the mechanical operations of spinning and weaving are completed, a certain amount of elasticity is gradually regained by the fibre ; and in washing, and otherwise dealing with either yarn or cloth previous to dyeing or bleaching, this improved condition is favoured. For some purposes, however, the yarn is treated with a strong alkaline solution, which gives it additional rigidity and hardness. We have heard it stated that mule-twist, which is the softest kind of cotton yarn, may thus be practically all but converted into another, resembling hard or water-twist.

Such is a general account of the preparation of cotton for the numerous purposes to which it is now applied. One hundred years ago, our manufacturers were far behind even the Hindoos in producing either yarn or cloth ; and even now, we must confess that the women of some parts of India can compete with our highest-class machinery in the production of what are called "fine yarns."

It will be unnecessary here to enter into a description of the various processes, by which wool, flax, hemp, &c., are converted into forms fit for use as clothing, &c., as the processes generally resemble those adopted in the case of cotton, with the exception of silk.

These will be hereafter discussed in detail, and we now pass on to consider the use and progress of the art of dyeing, bleaching, &c., as processes necessary to convert, or perhaps rather fit the results of our textile products into articles for garments, and other purposes.

Dyeing, Bleaching, Calico printing, &c.,—Ancient writers, both in sacred and profane history, frequently allude to the art of dyeing as one well known in their day. The allusions to "purple and fine raiment," to "dyed garments," to "cloth of many colours," &c., are numerous in the Bible. In a work, by the late Dr. Kitto, after an allusion to the antiquity of this art, and to the pre-eminence attached by the ancients to *purple* beyond every other colour, it is remarked:—"It is important to understand that the word purple, in ancient writings, does not denote one particular colour. Pliny mentions the difference between some of the purples: one was pink, approaching to a scarlet, and that was the least esteemed; another was a very dull red, approaching to a violet; and a third was a colour compared to coagulated bullock's blood. The most esteemed Tyrian purple seems to have been of the last colour; we say the most esteemed, because it appears that even the Tyrian purple was not one particular colour, but a class of animal, dyes as distinguished from vegetable, varying in shades of purple, from the most faint to the most intense. It is to be understood, however, that the Tyrian purples were more esteemed than any other colours, although they differed in degree of value. Of the vegetable purples we know nothing; most of the information relates to the purple of the Phœnicians: their dye was obtained from several varieties of shell fish, comprehended under two species; one (*Buccinum*) found in cliffs, and the other (*Purpura, or, Pelagia*) which was the proper purple-fish taken at sea. The first was found on the coasts of the Mediterranean and Atlantic, and locally differed in the tint and value of the dye which they furnished. The Atlantic shells afforded the darkest colour; those of the Italian and Sicilian coast, a violet or purple; and those of the Phœnician coast itself, so general on the southern coast of the Mediterranean, yielded scarlet colours."

We have no reliable data on which to form any opinion as to how the Tyrians made their dyes permanent, that is so that they could resist the ordinary processes of washing. In our day the use of what are called *mordants* (Latin *mordere*, to bite) is universal. This use is easily explained. If a piece of white calico be dipped into common black, it will, for a time, appear black. But it is not dyed, it is only stained, for on washing the black speedily disappears, and a brown colour, well known as an *iron-mould*, remains. If, however, the cloth be just dipped in a solution of some iron salt, and subsequently into an infusion of logwood, sumach, &c., a *permanent* black is produced, because the iron, acting as a mordant, has rendered the colour insoluble in water. Hence the use of mordants in dyeing, calico-printing, &c.

For many centuries dyers obtained their colours from animal and vegetable substances alone. The Tyrian purples, as already explained, were chiefly obtained from a molluscous animal. In regard to vegetable sources, they presented themselves in great abundance, but the majority of them did not come into general use until comparatively recent days. A list, and the use of these as now employed, will be given in a future chapter. Then, again, certain insects have been employed, such as the cochineal, lac and kermes, and these sources of colouring matter have been long familiarly known in the countries where such creatures are indigenous.

But one of the most interesting discoveries of modern times, is that of extracting colours capable of use in dyeing from certain kinds of coal. This has resulted in entirely revolutionising all the previously known processes of the dyer, and, in respect to the time occupied, hours take the place of weeks formerly required to produce similar colours from animal and vegetable sources. Then again as regards economy; the coal-tar dyes are capable of producing colours on textile fabrics at almost a nominal price. For example, we have known from eighteen pence to two shillings per pound paid for dyeing cotton-yarn of a rose tint, which may now be done for threepence or fourpence. That coal is of vegetable origin is an opinion now universally agreed in by all competent judges of the matter. Frequently we meet with fossil plants as perfect in their form, in respect to leaf, stem, &c., as if they were still growing. The stems of trees of great size, indeed, have been discovered completely converted into coal. But it is chiefly to the fern tribe of plants, as far as we can judge, that the formation of the coal, in this country at all events, is due. In the carboniferous era—that is, the period at which the plants flourished from which our coal has been formed—ferns must have been exceedingly more abundant, both in quantity and variety of species, than at the present day. At least three times as many species have been found, fossilised as coal, than now grow in Great Britain.

A careful chemical analysis of coal, also shows that it must have been of vegetable origin, for it yields chiefly carbon, united with comparatively small quantities of oxygen and hydrogen; and, in certain cases, nitrogen—apart from various mineral matters, such as alumina, iron, sulphur, phosphorus, arsenic, &c., that must be considered as simply accidentally, but more or less universally, present. The fact of iron and sulphur being met with in coal, also indicates its vegetable origin, as most of the fossils, constituted of iron pyrites, and so abundant in the Isle of Sheppey, at the mouth of the Thames, are, doubtless, the result of the replacement of vegetable substances by those elements.

There is nothing, however, taught us by chemical analysis that would lead to the supposition of coal being capable of producing colouring matter. Many of our readers may have met with the ridiculous account, some time ago largely distributed, that the first suggestion that led to the discovery of coal colours, was made by the colours afforded by tar dropped on the surface of water. It is true that a thin film of tar on that liquid affords the most beautiful colours. But this is simply due to the fact, that tar becomes of such extreme thinness, as to only be capable of reflecting certain colours to the eye, dependent on the thickness of each film. The same result may be produced by the soap-bubble, which, when first blown, gives a red tint; but, as it gets thinner, gradually affords orange, yellow, green, blue, violet, and all intermediate tints, till at last it appears black, being then too thin to reflect light at all. Similarly, if we press a double convex lens on a piece of plate-glass, the same series of colours are afforded, called Newton's rings: and the polariscope gives similar results. It is evident, therefore, that the simple production of colour from tar, in the manner already indicated, has no connection whatever with the production of coal-dyes; and the first discoverer of them might just as well have expected to find yellow soap, or a glass lens, in a lump of coal, as to have had thus suggested to his mind the existence of colouring matter therein.

Like all other discoveries of importance, that of the coal-dyes was the result of scientific induction, exercised on previously known facts. We are not aware of any really beneficial result that has arisen from the application of science, which could properly be called accidental. An old legend (for we cannot call it better in respect to its value) accounts for the discovery of the laws of gravitation by Newton, as having resulted from his "accidentally noticing the fall of an apple from a tree." Now, since the days of Adam, apples, when ripe, have had the same habit; but only one Sir Isaac Newton has existed. Similarly, all our great additions to scientific laws have been seed falling on good ground, bearing fruit "an hundredfold."

In respect to the production of dyes from coal, we may briefly give some account of the various products that arise from its dry distillation. The first result of heating coal in the gas-retort, is to drive off the uncombined water that condenses in the ordinary mode of gas-making in the hydraulic main. As the heat is increased, numerous volatile products are given off, and, with few exceptions, are condensed. The permanently gaseous portion consists of various "hydrocarbons;" that is, gases composed of hydrogen and carbon only, but in various proportions. The most important of these is "olefiant gas," to which the illuminating power of our coal gas is chiefly due. Besides this, is the "light carburetted hydrogen," similar to what is called "marsh gas," given off, at certain seasons of the year, from large extents of land covered with decomposing vegetable matter, and, in fact, chemically passing into the condition of coal; carbonic oxide, an inflammable gas, composed of oxygen and carbon, and well known in producing the blue flame in our domestic fires, brick-kilns, &c.; carbonic acid gas which we observe as producing the gas-bubbles of beer, champagne, and other effervescent liquors; and some others, to which we need not direct attention.

But of most importance are those products which are condensible, which include ammonia; some compounds of cyanogen that may be used in producing Prussian blue, photography, and for other purposes; tarry matter, naphtha, and some naphthaline compounds, &c., &c. These are collected in the liquid state, being more or less condensed by the water in the main. Chemically speaking, these are mostly compounds of hydrogen and carbon, varying in the proportion of each element that they contain—not accidentally, however, but according to an invariable law, which the scientific chemist recognises as pervading all compounds of what he terms an organic nature.

By distillation of these mixed products, ammonia, as the most volatile, is first obtained; and it is a very valuable product for a variety of purposes. The pungent odour of the lady's smelling-bottle; one of the most valuable manures for the farmer's use; and the alkali that is

used to scour wool, are all found in this first product of gas tar distillation. Naphtha next passes over; and within this is benzole, which we may consider as the basis of our coal-tar dyes. It exists in coal-tar naphtha to a varying extent, and may be separated from it either by distillation, or by exposing the naphtha to a temperature equal to the freezing-point of water. This *Benzole* has a smell much resembling smoke or gas, and is now commonly sold as a substitute for turpentine; as a solvent of india-rubber; and is largely used to clean gloves, silks, &c., by those who comprise dyeing and cleaning in the same business.

By acting on the benzole with nitric acid, we can obtain a compound called nitrobenzole, which has an odour resembling that of bitter almonds; and, indeed, can be substituted for that liquid in confectionery, scented soaps, and other similar purposes. Strange to say, that a vegetable product, well known as gum benzoin, can also afford benzole; and, still further, the chemist recognises a direct relation between this and the bitter almond oil obtained from the fruit of the almond tree, cinnamon oil, and some other compounds that we need not at present allude to. In fact, their chemical constitution is so analogous in each case, that, by the law of substitution, as it is termed in science, we can at once see the whole of these compounds alternately separated in nature, yet completely joined together in their philosophical aspects. To the man of science this fact is of infinitely greater importance than the discovery of the aniline dyes; but, as we are addressing the practical man alone, we must not dilate on this subject.

On adding nitric acid to benzole, a violent action takes place; and when this has ceased, a yellow-coloured liquid results, which is the nitrobenzole that we have just alluded to.

We here notice the addition of another element to those constituting benzole—namely, nitrogen; for benzole only possesses carbon, hydrogen, aud oxygen; hence its chemical character is completely changed, and, consequently, its physical characteristics also.

Aniline is contained in the coal-tar liquor in but small quantities. It is found in indigo, and even in human urine; but all these sources would be far too expensive to permit of its extraction for commercial purposes. We can, however, by the action of acetate of iron on the nitrobenzole we have been describing, and by other methods, convert it into aniline; and this new compound, consequently, may become the base of the various beautiful colours to which we have frequently alluded.

Aniline, in part, partakes of some of the properties of an alkali, as potash or soda; but it does not change yellow vegetable colour to that of a brown tint, as potash, soda, and ammonia can do. Prepared either by the acetate of iron, as just stated, or from the nitrobenzole dissolved in alcohol, and treated with ammonia and sulphuretted hydrogen until all sulphur ceases to be precipitated, the liquid being distilled with caustic potass, aniline is produced as a thin colourless liquid, having an odour somewhat resembling that of wine, and an aromatic taste. It is soluble in water; but especially so in alcohol (spirits of wine) and ether; hence the occasional use of the "spirit" in effecting its solution, in certain forms, for dyeing purposes.

In a scientific point of view, aniline presents many peculiarities and analogies; and its examination, and the fresh combinations that have arisen from its discovery, have given rise to an extensive series of results, that have been termed substitutions of the aniline series; but into the discussion of these it will be beyond our purpose to enter, because it would involve, on the part of our readers, an amount of chemical knowledge that, in writing these pages, we presume they do not possess.

The colours that have been obtained from aniline, in various modifications, embrace most of those previously procured from dye-stuffs of a vegetable and mineral nature; as, for example, various shades of red, blue, and all intermediate tints. Amongst the most important are the following:—

Magenta, a well-known and highly popular colour, is obtained as a dye-material by acting on aniline by the bichloride of tin. Violent action ensues on their mixture. After some time, the heat generated raises the liquid to a boiling heat, when a deep red, but, apparently, a black liquor, from the depth of colour, is produced. By the action of nitrate of mercury on aniline, a similar result is afforded. The dye-material is partially soluble in water and alcohol, but insoluble in ether or naphtha.

Emeraldine, or aniline green, is the result of the action of chlorate of potash upon a solution of aniline in hydrochloric acid; and hence the oxidation of the aniline is effected. Violine is produced by oxidising aniline, which is effected by first heating two equivalents of sulphuric acid.

with one of aniline and water, forming a sulphate of aniline, and decomposing this by means of the binoxide of lead. The purple liquid resulting from this is boiled with potass, when the colouring matter is precipitated. To purify it from any extraneous matter, it is washed with water, and dissolved in tartaric acid. After evaporation, it is precipitated by an alkali, and a solution of alcohol (spirits of wine) may then be made of the precipitate, which affords a bronze-coloured powder on the spirits being evaporated. Roseine is prepared also by the action of the binoxide of lead on the sulphate of aniline; two equivalents of the binoxide being employed to one of aniline. The mixture is boiled for some time, and, after evaporation, the dye may be obtained as a precipitate by the addition of an alkali. It is soluble in water, but not in naphtha, and affords a beautiful crimson colour as a dye. A rich purple dye is obtained from aniline by mixing an equivalent each of the sulphate of aniline with the bichromate of potass. The black precipitate is purified by coal naphtha from all resinous matter, and then dissolved in spirits of wine. By distillation the dye is left as a mass of a brown colour. It is readily soluble in spirits of wine, and less so in hot water, but is insoluble in ether or naphtha. A fine blue dye is obtained by heating one part of bichloride of tin with about two of aniline to a temperature of 350° Fah. in a closed vessel for about thirty hours. A blue substance, soluble in water, spirits of wine, naphtha, and acetic acid is afforded, technically called the *Bleu de Paris*.

Numerous other coal-tar products used for dying purposes might be mentioned, but one of the most important of modern inventions is that of the production of *Alizarine*, produced by coal-tar distillation, in a manner which will be explained in a future chapter. Formerly madder and safflower were chiefly used for the purpose of dyeing reds, especially the former for producing what is called "Turkey-red." By means of sulphuric acid *Garancine*, was extracted from the powdered madder root. This product or proximate principle, contains two others, namely, *Purpurine* and *Alizarine*. The latter is now exclusively obtained from coal-products, and consequently the growth of madder, which was a feature of agricultural industry abroad, has so far declined, that it has been found necessary to replace it by crops of beet-root, now extensively used in producing sugar.

We have thus briefly described the revolution in the dyer's art, which has taken place owing to the introduction of coal-tar dyes, but as, under the article of *Dyeing*, it will be necessary to describe many of the old sources of colours still in partial use, the following more detailed accounts of the history of the art may be perused with advantage.

Early processes of dyeing, in respect to the Greeks and Romans, were in a crude state in the time of Alexander; but they were well acquainted with the use of the insect *Kermes*, as a source of red dye, it being a native generally of Southern Europe, many parts of Asia, and Northern Africa. In the days of Pliny, the eminent naturalist, it was largely employed; and alum was well known in his time, but it is a matter of question whether it was in any way used as a mordant; although the general use of mordants was known at that period. Madder, woad, dyer's broom, alkanet, walnut bark, and some species of the pod-bearing order, or *Leguminosæ*, were in use for dyeing purposes. Indigo seems also to have been known.

However deficient the ancients may have been in respect to purely chemical knowledge (and we have no reason to believe that they possessed much of this), it is evident, from the remains of Pompeii, and evidenced by other sources, that they were capable of producing excellent dyes, and most permanent pigments. It is true there were greater advantages in their favour in respect to the purity of the air, and much drier atmosphere, which existed, and still exists, in Southern Europe, Northern Africa, and the Levant coast of Asia Minor, than we can boast of—circumstances highly favourable to the permanency of colour in any form. Still we must give the palm of merit to the Romans, and other nations, existent and partially civilised some two thousand years ago, for great practical ability in colour-production. History, sacred and profane, fully carries out this fact in its details of economical processes, &c. Unfortunately, the chemical analysis of vegetable colours is all but impossible in the condition that they have been kept from antiquity, and as now preserved in our museums, or probably the dyer of the present day might receive some valuable hints from his predecessors of old.

The discovery of America resulted in a great and invaluable accession to the list of dye-materials. In 1518, the Spaniards found out the native use of cochineal, in Mexico; and, not long afterwards, its use was introduced into Egypt. We are indebted to Mr. Barlow for the following account of the discovery of its uses in connection with a solution of tin, which,

although apparently accidental, is simply another proof of what we have repeatedly observed—that no really valuable discovery, although based on accident, can be considered in its development as solely due to that cause; for we shall see that the person who made the discovery was actually engaged in researches tending towards that direction. Mr. Barlow remarks as follows:—

"The tincture of cochineal (that is, a solution in spirits of wine) alone yields a purple colour, not very pleasant, which may be made into a most beautiful scarlet by a solution of tin in *aqua-regia* (nitro-hydrochloric or nitro-muriatic acid). Mr. Rühlenkamp, of Bremen, one of the most learned dyers in Germany (1830), and who has studied with great care every improvement in the art, gives the following history of the modern scarlet dye:—The well-known Corneliue Drebbel, who was born at Alkmaar, and died in London in 1634, having placed in his window an extract of cochineal, made with boiling water, for the purpose of filling a thermometer, some *aqua-regia* dropped from a phial, broken by an accident, which stood above it, and converted the purple dye into a most beautiful dark red. After some conjecture and experiment, he discovered that tin, which had been dissolved by the *aqua-regia*, was the cause of the change. He communicated his observation to Küffelar, an ingenious dyer at Leyden, who was afterwards his son-in-law. The latter brought the discovery to perfection, and employed it some years alone in his dye-house, which gave rise to the name of Küffelar's colour. In the course of a little time the secret became known to one called Gülich, and also to another person of the name of Van der Vecht, through whom it became known to the celebrated Giles Gobelin, at Paris, who there erected a large dye-house. About the year 1643, a Fleming, named Kepler, established the first dye-house for scarlet in England, at the village of Bow, near London, on which account the colour was called, at first, 'Bow dye.'"

About twenty-five years after the introduction of cochineal colour as a dye into this country, Hooke, the celebrated and bitter opponent of Newton—the "Jack of all Trades" in experimental science, and master of none—if we may be so allowed to express our opinion of that man and his writings—discovered a method of printing simultaneously, yellow, blue, green, and purple colours on a piece of calico, that stood the action of hot soap and water; and which he exhibited at a meeting of the Royal Society, in November, 1669. Hooke had been, two years previously, requested to translate a work on dyeing, by that society. We may here mention a name that has long been identified with art-progress; and one of the family, the late Marquis of Lansdowne. has been by no means behind his ancestry in that respect. Sir William Petty, who founded the House of Lansdowne, was one of the first members of the Royal Society, to which he presented the model of a double-bottomed ship, designed to sail against wind and tide. He was a man of most varied accomplishments; studied at Leyden, Paris, and Oxford; was simultaneously professor of anatomy and music (the latter office being held in connection with Gresham College); secretary to Henry Cromwell, in Ireland; and author of numerous works on science, trade, mathematics, chemistry, political economy, &c. But, for our purpose, we have chiefly to draw attention to the fact that he was author (*cir.* 1667) of the first work published in the English language on the art of dyeing. This was entitled *An Apparatus to the History of the Common Practice of Dyers.*

For a long time after this period the art of dyeing made little or no progress in this country. On the contrary, however, in France every attempt was made, consistent with the then condition of chemical science, to carry on the art to the highest degree of excellence; and it was placed under the special supervision of the government, by which its pursuit was carefully fostered by encouraging investigations, and assistive legislative enactments. In this country, towards the close of last century, the celebrated chemist, Dr. Henry, rendered essential service to its progress by original investigations, and by the publication of the results he arrived at. Living at Manchester—then, and ever since, the centre of the cotton, dyeing, bleaching, and printing trades—he availed himself of numerous details and facts to improve various processes. Amongst his productions in this respect, we may especially notice a paper that he communicated to the Philosophical Society of Manchester, entitled, *On the Nature of Wool, Silk, and Cotton, as objects of the Art of Dyeing; on the various Preparations and Mordants requisite for these different Substances; and on the Nature and Properties of Colouring Matter.* In this he propounded most important facts and views in respect to the chemical and practical pursuit of the art, and that of calico-printing, especially pointing out the value of the acetate of alumina, in place of common alum, as a mordant for calico-printing and dyeing, in regard to cotton.

Also, towards the close of the last century, Dr Bancroft rendered great service to the dyer by publishing a work that gave a *résumé* of the discoveries and applications made by continental chemists, such as Macquer, Dufay, Hellot, and Berthollet. He described the action of tartar, in combination with a tin solution, as productive of scarlet with cochineal. He also was the first to introduce the use of quercitron bark as a dye-stuff for producing yellows, then a discovery of considerable importance, but since tempered considerably in its value by more recent discoveries of material, and improved chemical processes.

Within our own time, Dr. Ure, Mr. Walter Crum, of Glasgow, and others whose names it would be invidious to select, have combinedly aided to bring the arts of dyeing and calico-printing to the perfection in which they now exist. But, as we have already stated, the greatest discovery and application of chemistry, in both of these arts, have been those in respect to aniline, or coal-tar colours, that bid fair, by their beauty, brilliancy, permanency, and ease of manipulation, to drive most other sources of dye-colour out of the field.

Having thus given a general outline of the history and progress of the dyer's art, we next turn to the subject of bleaching, which illustrates how much science has done for the advance of the Arts and Manufactures.

Bleaching.—The art of whitening all kinds of textile fabrics, is one, like that of dyeing, of ancient origin; and is equally, and was so, dependent on the aid of chemistry. But, certainly, we must give more credit to the bleacher, in availing himself of this science in improving his processes, than we can possibly do for the dyer. We have already intimated that, to a large extent, dyeing is an empirical art; often barely dependent on principle in respect to its practice, and still less characterised by precision. Not so with bleaching. Every step should be organised and dictated by strictly scientific rules, because they aid directly the speed and certainty of the process. The system of cotton bleaching carried on before the discovery of the use of chlorine, was one exceedingly tedious, uncertain (we should fancy, unprofitable), and dependent, like the making of hay, on sunshine. Barlow thus describes it:—

"The first operation in the old system, as in the new, is to remove a substance termed sowens (he refers to woven goods), which is a paste made of flour and water, used during the weaving, for the purpose of closing down the fibres of the thread, and thus allowing them to pass more freely through the reed and harness (of the loom). This consisted in steeping the goods in a vessel of lukewarm water, till a gentle fermentation took place, which usually required about twenty-hours. The cloth was then taken out, and well washed in a current, which removed a considerable quantity of the filth without the use of alkaline leys.

"The goods were then boiled in a vessel containing a solution of potash (pearlash), and furnished with a winch and rollers, by which the cloth could be moved about in the liquor, and by that means be thoroughly impregnated with it. This was continued as long as the liquor appeared to abstract any colouring matter from the cloth, which was then taken out, and well washed in water. The use of this process depends upon the properties which alkaline salts (substances, not salts) possess of uniting with the oily and resinous matters which are either attached to, or are a constituent part of the vegetable fibre.

"The next operation is termed *bucking*, and is similar in principle to the last, although a more powerful application of it. The goods are placed in a vessel called the "bucking-tub," and a powerful solution of the alkaline ley is poured upon them from a vessel, where a quantity is kept constantly boiling. When the goods are thoroughly impregnated with the boiling ley, it is allowed to pass off into an iron vessel, whence it is pumped back again to the boiler, and returned hot again upon the cloth; which process is continued for some time. The cloth is then taken out, well washed from impurities, and laid upon the ground, to be whitened by exposure to the atmosphere.

"In order to dissolve and remove any metallic or earthy (mineral) matter, inherent in the cloth, or which may have been derived from the impurity of the alkaline solutions, an operation termed souring is employed. The goods are immersed, for about the space of twelve hours, in a mixture of sulphuric acid and water, well incorporated, the proper strength of which should be about (equal to) the acidity of lemon-juice; and was usually determined by the taste. The goods may be put into this acid (solution), either in a wet or dry state; but the best plan is to immerse them in the evening in the acid liquor, cold; to let them remain covered with it all night; then in the morning to make a fire, and bring the liquor to a blood-heat, in which state the goods should have a few turns, in order that every part of them may be equally exposed to the fluid.

The goods are then wrapped round the winch to strain them a little, to prevent an unnecessary waste of acid, and afterwards carried to the wash-wheel or river, to be washed till there is no acid perceptible to the tongue remaining in the cloth (or yarns). It is a remarkable circumstance, that cloth may remain immersed (for) a considerable time in strong acid liquor without rotting; but that if exposed to the air, or the heat of a stove, if a very small portion of the acid remains on the cloth, it becomes so concentrated by heat as to damage the material immediately; too much attention cannot, therefore, be paid to this point.

"The operation of bucking was repeated for some cloths a great many times, each time requiring, with the subsequent operations of leying and watering in the bleach-field, the period of a week. The first two buckings were with very strong ley, which it was (subsequently) necessary to diminish in strength, to prevent injury to the cloth.

"These operations could be carried on only during the summer months; and during four months in the year, bleaching by the old system was entirely suspended, and the capital of the manufacturers or proprietors of the goods (was) locked up, and useless: the immense time (during) which the goods were under operation, was also the means of a great consumption of capital. Cotton goods which required from four to six applications of alkaline leys, consumed as many weeks in bleaching; while linens, which could not be bleached by less than from twelve to twenty applications, could scarcely be brought into a marketable state in less than six months."

Such is a general outline of the old method of bleaching, which, although abolished for several years, is yet well remembered by many of those who had formerly to suffer for its uncertainty, and lengthened operations. Chemistry at last presented us with a method by which we can now effect a far better result in as many *hours* as it formerly took *weeks* to accomplish—nay, we might say almost months.

Thanks to Scheele, the celebrated Swedish chemist, the discovery of chlorine placed in the hands of the bleacher an agent far superior, in its effects, to that of simple exposure to air, light, and moisture, on which the whole system of bleaching chiefly depended. It is not certain, however, as to whom we are indebted for the first application of this element, for practical purposes, in regard to bleaching. It is stated by Barlow, that Scheele wrote to our countryman, Kirwan, informing him of his discovery of chlorine, and this special application of its bleaching powers; that Mr. Kirwan mentioned the subject to Mr. Taylor, then secretary to the Society of Arts, and this independent of any knowledge that the celebrated chemist, Berthollet, had of the process, and to whom some ascribe its discovery. Concluding the narrative of this statement, it is added, that, in 1788, a whole piece of calico, in the state received from the loom, was bleached, printed in permanent colours, and produced in the market at Manchester for sale; having undergone all these processes in less than forty-eight hours. According to the same authority, however, it would seem that we are much indebted for the early progress of bleaching by chlorine to Berthollet, whose exertions in carrying out the application of chemistry to dyeing, &c., have been of such great value to the practical man.

At first, mere immersion in an aqueous solution of chlorine was adopted; but this method is both uncertain and wasteful, for the chlorine soon decomposes the water, to form hydrochloric acid with its hydrogen; and not only so, the watery or aqueous solution is generally too weak to be of any practical value. Next, therefore, to the discovery of chlorine by Scheele, we are indebted to Mr. Tennant, of Glasgow, who was the first (*cir.* 1798) to introduce the use of chloride of lime, or bleaching powder, in which the chlorine is weakly combined with lime; and in that condition is of the highest service to the bleacher. His descendants still carry on business near that city, and rank amongst the most extensive and prosperous chemical manufacturers of the kingdom.

Whilst, however, our modern method of bleaching so greatly differs from that previously adopted, it is by no means certain that the actual chemical processes differ. Dry chlorine—that is, the gas perfectly free from moisture—has no power whatever of abstracting the colour of vegetable bodies; and that there is no doubt but at least the presence of one constituent of water is absolutely essential to our modern methods of whitening or bleaching cotton fabrics.

The chief source, and, indeed, the only commercial one, of chlorine, is common salt, which chemists view as a combination of that element and the metal called *sodium;* hence our table salt is denominated, in the laboratory, *chloride of sodium.* By adding sulphuric acid to this, a compound of chlorine and hydrogen is given off, familiarly known as spirits of salts, or

muriatic acid; but now universally called, in accordance with our chemical nomenclature, *hydrochloric acid.* If this acid be heated with the black oxide of manganese, or—what is equivalent thereto—if common salt, sulphuric acid, and the black oxide of manganese be all heated together in a proper vessel, chlorine gas—so called from its yellowish-green colour—is given off. In preparing the bleaching powder, this gas is absorbed by lime, over which it is allowed to pass, until what we usually call saturation is effected; that is, the lime takes up all the chlorine that it can possibly combine with.

What the precise effect of chlorine is in bleaching cotton or linen goods, is not known. It will be our business, subsequently, to enter into all details of the process of bleaching. It does not seem, as far as chemical analysis has yet shown us, that bleached cotton differs essentially, or, perhaps, we should rather say, constitutionally, from that in the raw state. And, thus far, the results of bleaching are different from those that arise from the action of nitric acid on cotton, as seen in the conversion of this material into what is familiarly known as *gun-cotton*, now much used for blasting and other purposes. In any case, we find that the removal of colouring matter is effected, chlorine having great power in destroying such forms of vegetable matter.

If the chlorine is presented in a highly concentrated condition, however, the destruction of the fibre is sure to ensue; hence, in bleaching operations, it is of the utmost importance to regulate the strength of the solution of chloride of lime employed; and to prevent—what very often happens—the contact of solid pieces of that substance with the goods under process of bleaching. In respect to yarn this point is of even still greater consequence; because if the tenacity of a portion of the fibre be destroyed, a whole hank may become valueless. A branch of chemical analysis is, therefore, necessarily of frequent practice in the bleach-house. It has received the name of *chlorimetry*, or *chlorometry;* and has for its object to ascertain the strength of chloride of lime solutions employed for bleaching purposes. Its details will be described in a subsequent chapter.

As a matter of curiosity we give the following engraving, which illustrates the custom of washing and bleaching formerly, and even now in use in certain Eastern countries (See Fig. 32).

But a still more curious illustration, so far as our country is concerned, is afforded in the

Fig. 32.—Egyptian Women Washing and Bleaching at the Nile.

following cut (Fig. 33). It is copied from a curious drawing contained among the Harleian manuscripts, and dated 1582. This seems to represent a public washing-ground, with a fire and the necessary apparatus out in the open air. On the right hand side there are evidently shown long pieces of linen, stretched out at full length, and lying on a grassy sward to bleach. The drawing itself exhibits some rather questionable points as to perspective, but it is valuable as representing the art of bleaching as carried on at the time it was drawn.

Linen and hempen fibres generally may be bleached by processes already described; but for "Irish linens," and "cambrics," the old method of "grass-bleaching"—that is, by the action of the air and moisture—is still employed. We have already described the old method, as applied to cotton; and as the details and principles of those adopted in bleaching linen are similar, when the open-air plan is adopted, we need not again go into further explanation.

Fig. 33.—Public Washing and Bleaching Grounds, 1582.

Wool and silk scouring, and bleaching, and that of mixed fabrics of cotton and wool, differ much, in principle and detail, from the processes just previously described; for neither acid for souring, nor chloride of lime for decolouration, are admissible. Wool contains, on the surface of its fibres, an oily and adhesive matter, that resists the unaided action of water, either hot or cold; but which can be removed by alkalies, such as pearlash (potash) or soda. But both these, as a caustic, would, if applied, materially injure the tenacity of the fibre, and unnecessarily decrease the weight of the wool scoured by them; hence a double source of loss would be occasioned. If practicable, stale urine, by affording ammonia, is an excellent and safe source of alkali for such purposes; but, usually, the supply is too limited to permit of its exclusive use; and soap, with ordinary "washing soda," in crystals, are employed in solution with hot water. By such means the fatty matters are readily removed, and the surface of the fibre left free for bleaching or dyeing purposes, abundant washing in water being had recourse to. The temperature of the soap and soda solution is important, for two reasons; one being, that too high a temperature would shrink the fibre, yarn, or goods; and the other is found in the fact, that a high heat so far stimulates the action, both of the soap and soda, as to injure the articles. A heat but little over what the hand can bear—say not exceeding about 145°—is sufficient; and it is the safest to judge of this by using the thermometer. It is usual to stretch all woollen articles by mechanical means, as much as possible, during the process of scouring, so as to prevent contraction, and also the action of the felting property, by virtue of which each fibre tends to unite firmly to those adjacent to it—a circumstance of great value during the finishing of cloth, but a cause of much loss under other conditions. Some kinds of wool lose enormously during scouring—we have known as much as 30 per cent.; and this, on high-priced wool, is a matter of great importance, and causes much

loss to the manufacturer, who, therefore, takes every proper precaution to keep it within the narrowest limits possible.

Silk is scoured by similar means to those adopted for wool; but, as the individual fibres are much more delicate and finer, greater care is required both in the chemical and mechanical details; more especially as any loss it sustains increases, in pecuniary value, many times above that found in even the cost of the best wool.

Although chlorine is useless for bleaching any but vegetable materials, we have, in another agent, *sulphurous acid*, that which supplies our want. Sulphurous acid contains one equivalent less of oxygen than sulphuric acid; and is readily produced by burning sulphur or brimstone in air. As is well known, it has a most suffocating odour, arising from the acid fumes. Under the formerly adopted method, either woollen or silken goods were, after scouring and moistening, placed in a close chamber, in which was burning sulphur—so folded, or rather hung, that the fumes had free access to every part of them. Another method was that of using liquid sulphurous acid, by decomposing in water certain salts, that thus afford sulphate of soda and the acid, both dissolved in the liquid. By the method of Mr. Thom, of Manchester—once of general use, and especially of value in mixtures of cotton and wool, as *mousselines-de-laines*—the goods are passed over a number of rollers, in an air-tight chamber filled with sulphurous fumes, produced by the combustion of sulphur; and their whitening is effected in almost as many minutes as formerly hours were needed. On removal from any of these sulphuring arrangements, the goods are carefully washed; and, if to be sold in the white state, are slightly blued, like cotton, with indigo, to remove or mask any yellow shade they may possess, or are likely to attain in time.

Such are the chief methods and processes in modern use for bleaching or whitening cotton, linen, woollen, and silken yarns or fabrics. Within the last fifty years, numerous improvements have successfully led to the perfection that now characterises the various operations we have described. In former days, when calico-printing was in its infancy, and the principles on which it was conducted were more mechanical than scientific (being also exceedingly rough in their results), an imperfectly bleached piece of calico was not so much objected to. But when chemistry, with all the delicacy of its precision in effect, and in the variety of colours also of an exceedingly delicate character, directs, or is involved in, the operations of the calico-printer, the cloth must be as perfectly free as possible from impurity of any kind, or it would be impossible to produce anything like a good result. This is especially seen in connection with the use of coal-tar colours already referred to at page xliii *ante*, which, in calico-printing, as in dyeing, have greatly taken the place of colours of vegetable origin.

Calico-printing.—The mode of conducting this art was known to the Hindoos long before anything of the kind had been practised in this country. One of the Portuguese merchants, who went to India several centuries ago, spoke with admiration of the "painted" cottons which the Hindoos produced. A Venetian merchant also, who travelled in India about 1560, speaks of the cotton-cloth as being "painted, which is a rare thing, because this kind of cloth show as they were gilded with divers colours; and the more they be washed the livelier the colour will show."

Father Cœurdoux, a missionary at Pondicherry, gave the following account of the mode practised by the Hindoos in printing, or rather painting their calicoes with colours. The cotton when taken from the loom, was worn next to the skin by the dyer and his family during a space of eight or ten days, after which it underwent several steepings, beatings, washings, and dryings in the sun. It was next soaked for some time in a liquid formed of curdled buffalo's milk and the astringent fruit of the yellow *myrobalans* (now largely used in dyeing, &c.). After the cloth was thoroughly impregnated with this mixture, it was taken up, squeezed, dried by exposure to the sunshine, rubbed, and pressed. Then ensued a process of painting, by drawing devices on the cloth with a pencil. The liquids used for this purpose were not colours or pigments, but mordants. The first was a mordant of acetate of iron mixed with some palm-wine, and thickened with rice-water: this mordant was applied to the figures or spots intended to become black. Then another mordant was applied to those parts which were to be red; this consisted of alum-water coloured with powdered sappan-wood and thickened with gum. When these processes were finished, the cloth was exposed to the hottest sunshine, to dry the parts where the mordants had been applied, and then it was thoroughly soaked in large pots of water to cleanse it from the loose or superfluous part of the mordants. A dye-vat was next prepared,

consisting of certain roots boiled in water, and in this dye the cloth was boiled for a long period. The parts which had received the alum mordant were made red; those to which the iron mordant had been applied became black; and the remainder, after being washed and bleached in the sun, became white.

There are not wanting many indications that this art, practised in one or other of the ways consistent with the object in view, has been known among other nations, in some cases from a remote period. Thus Pliny, while speaking of the arts among the Egyptians, says, "Garments are painted in Egypt in a wonderful manner, the white cloths being first smeared not with colours, but with drugs which absorb colour. These applications do not appear upon the cloths; but when the cloths are immersed in a cauldron of hot dyeing liquor, they are taken out a moment after painted. It is wonderful that although the dyeing liquor is only of one colour, the garment is dyed by it of several colours, according to the different properties of the drugs which had been applied to different parts. Nor can the dye be washed out."

The kind of goods which were first printed in Europe were a mixture of cotton and linen; and the printing was done confessedly to imitate the chintz pattern of India. The art advanced by slow degrees during the first half of the eighteenth century. The calico-printing trade, so far as regards this country, was carried on first in the vicinity of London. It was entered upon in Lancashire about the year 1764, and the second person who embarked in it there was Robert Peel. The history of this family, in respect to their position as Lancashire manufacturers, is interesting: and is thus given by Mr. Baines, in his *History of the Cotton Manufacture*:—"Mr. Peel was originally a yeoman, farming his own estate, and lived at Cross, afterwards called Peel-fold, near Blackburn. Being of an active and enterprising disposition, he began the manufacture of cotton: and he is mentioned as one of the first persons who tried the carding cylinder. He also took up the printing business; and I have been informed by a member of his family, that he made his first experiments secretly in his own house; that the cloth, instead of being calendered, was ironed by a female of the family, and that the pattern was a parsley-leaf. Stimulated by the success of his experiment, he embarked in the printing business with small means and convenience, and shortly afterwards removed to Brookside, a village two miles from Blackburn. Here he carried on the business for some years with the aid of his sons; and by great application, skill, and enterprise, the concern was made eminently prosperous. His eldest son, Robert, afterwards created a baronet, possessed strong talents, which he devoted assiduously to business from an early age, and thus contributed much to the success of the printing spinning, and manufacturing businesses; and in each of these branches the Peels soon took a lead in Lancashire. They eagerly adopted every improvement suggested by others, and many improvements originated in their own extensive establishments. As the elder Mr. Peel had several sons, Robert quitted his father's concern about 1773, and established himself with his uncle, Mr. Haworth, and his future father-in-law, Mr. William Yates, at Bury, where the cotton-spinning and printing trades were carried on for many years with pre-eminent success, and on a most extensive scale. Mr. Peel, the father, with his other sons, and another Mr. Yates, established the print-works at Church; and had also large works at Burnley, Sally Abbey, and Foxhill Bank; and spinning-mills at Altham, and afterwards at Burton-upon-Trent, in Staffordshire. So widely did these concerns branch out, and so liberally and skilfully were they conducted, that they not only brought immense wealth to the proprietors, but set an example to the whole of the cotton trade, and trained up many of the most successful printers and manufacturers in Lancashire. The history of the two houses, the Peels of Bury, and the Peels of Church, is indeed the history of the spinning, weaving, and printing of Lancashire for many years."

Block-printing was that first practised. The pattern was cut out of wood; the raised parts forming it, and the depressions, of course, not touching the cloth. One block would be required for each colour—just, in fact, as is now practised, so far as the mechanical details are concerned, in chromo-printing on paper for illustration of books, paper-hanging, and floor-cloth printing. Each colour is thus laid successively on the cloth. A young person supplies a brush, dipped in a vessel full of colour, spreading the latter over a kind of elastic cushion, in as even a manner as possible. The printer then presses the engraved block on the colour, and transfers it to the cloth, which is stretched on a flat even surface; and he is directed, in superposing each successive block of colour, by means of pins that project from the engraved surface of each. Thus the design is evenly printed, and one colour "registers" with another. (See Fig. 34.)

Another method, equally applicable to block-printing, is that of printing with mordants on a white surface. Thus, if, in place of colours, the printer used successively two blocks—say one covered with a mordant of acetate of alumina, and another of acetate of iron, both thickened by a similar substance, to prevent them running—no colour, of course, could be produced until the cloth is immersed in a bath—say of madder—when a red and a black would be afforded. But as we are now dealing with the early methods, rather than the chemistry of modern ones, we will, for the present, only suggest the plan, and leave its explanation for further description.

Another method, somewhat resembling the preceding, but differing in certain mechanical details, was that of printing by the press; but, as cylinder-printing has superseded all other plans, except that by which Bandanas are produced, we may omit any description of press-printing.

Cylinder-printing is a process that, once properly set in action, requires little attention, and is quite continuous in its operation. The essential part is a copper cylinder, on which the pattern is engraved. The hollows produced by the engraving receive the colour from a trough, in which it revolves; and all communicated to the unengraved surface of the roller is removed by a metal knife or band, that presses on its surface, and so strips all the colour off, except that contained in the engraved hollows. The cotton passes the roller, pressing on it, and so receives the colour from the engraved hollow portion. In the following cut (Fig. 35), an illustration of cylinder-printing is afforded. The calico is wound on a drum placed behind the machine, whence it passes to, and presses against, the engraved surface, from which it is drawn over-head.

Fig. 34.—Calico-printing by the Block.

The late Dr. Calvert, in a lecture on calico-printing, observed, respecting recent improvements in the construction and use of cylinder-printing machines :—"Although, of late years, many improvements have taken place in the construction of printing machines, most of which are of too technical a nature to be described, ... still, there are one or two which have exercised so marked an influence on the general progress of the art of calico-printing, as to require notice. One of these is the arrangement by which an independent motive power is provided for each machine, instead of connecting all machines in an establishment with one steam-engine: the advantage thus gained by the machine-printer is to regulate the speed of his work at any moment; at the same time, the spent steam is made to pass into the drying machines, thus effecting an economy, and drying the pieces more quickly. Another improvement is the greatly increased number of rollers which each machine is adapted to work; thus there are some Lancashire houses which can print from sixteen to twenty colours simultaneously. Messrs. Onfroy and Co., of Paris, exhibited at the last Exhibition (1862), a most ingenious means of obtaining reserves on fabrics, which improvement is the more advantageous, the chemical reserves generally in use being imperfect in their composition, of difficult application to the fabric, and still more difficult of removal. The ingenious process of Messrs. Onfroy, consists in punching out patterns from a sheet of card-board lined with gutta-percha, in such places as are intended to remain white, or reserved. The card-board is then rolled on the pressing cylinder of the printing machine; so that when the machine is working, the parts of the pattern which have been cut out receive no impression; and thus form the reserve of the pattern. It is evident, that to obtain satisfactory results, the greatest precision must be observed in applying the card-board to the pressing cylinder, so that the engraving roller will only apply

where required. The great advantage of this mode of producing reserves is, that by employing a pressing roller of sufficient diameter, reserves of large surfaces can be easily obtained."

Having thus briefly described some of the most important arts in relation to our supply of food, clothing, &c., we next turn to some which, although apparently of less consequence, are still necessities of our modern condition of civilisation.

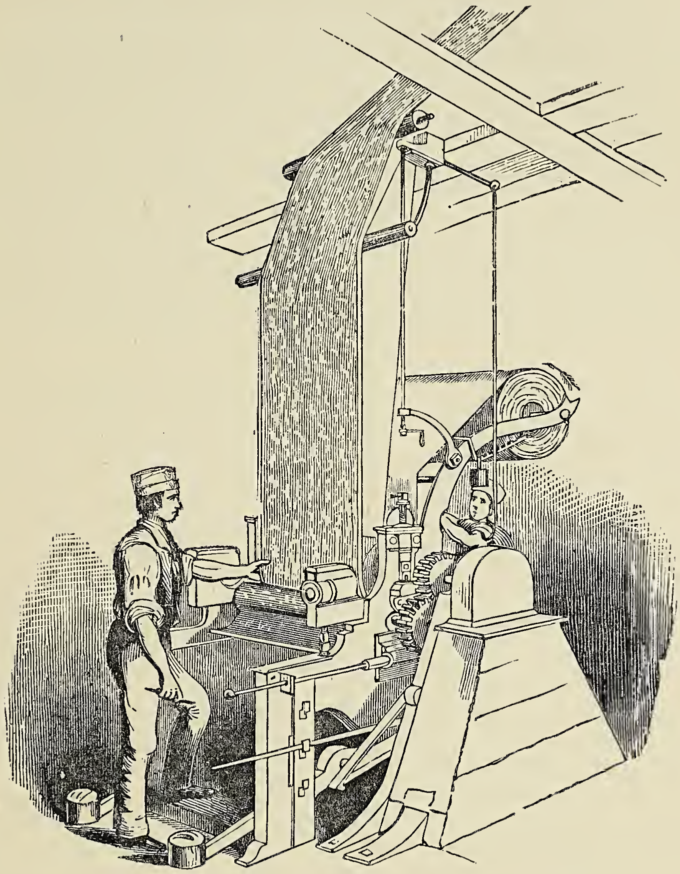


Fig. 35.—Calico-printing by Cylinder.

Brick, Pottery, Glass, &c.—As civilisation advanced in the early history of mankind, wants which had previously been satisfied in the crudest manner, became enlarged by intellectural culture. The dens and caves of the earth were, perhaps, replaced by huts made of the branches of trees, as is yet commonly done in some parts of Africa, and other uncivilised countries. House construction as a shelter from rain, wind, and storm, gradually led to the making of bricks. We read, for example, in the early pages of the sacred writings, of the builders of the Tower of Babel, who "said one to another, Go to, let us make brick, and burn them thoroughly. And they had brick for stone, and slime had they for mortar."—(Gen. c. xi, v, 3.)

It is evidently impossible to assign any specific date when any branch of the art of clay-burning (and that is the basis of the art of pottery) first became known to man. Psychologically, it is a matter of deep interest to trace out from their initiative the beginnings of human history in respect to art. But, in our day, the perfection to which all artistic efforts have arrived, casts on such a history a kind of haze. We feel satisfied with our own progress, and, as such, are incapable of tracing the steps that have led to it; hence the antecedents of our progress are left in oblivion, because of the dazzling effects of the light of modern genius.

A visit to the British Museum, in London, cannot but be productive of interest to any who

have a taste for searching into what man once was, and comparing his past with the present. Humanity, like personal identity, never entirely changes. To-day, the matter which forms the body of the man differs, chemically, in no respect from that which will form the same body two years hence. But, at the expiration of the latter period, the man will have lost every particle that at the present moment forms him. Just so in all the arts that man has invented. He takes the material as the earth affords it; he fashions it, in accordance to the progress of the art, into various shapes and forms. The latter carry their mental impress for ages, while the material is simply the *corpus vilum* on which the experiences of the human mind are tried.

It is by no means derogatory to the character of man that he attaches importance to matters apparently trivial. But who will complain that an individual should more highly esteem a brick from Babylon or Nineveh than the bank-note for any amount of the present day, more especially if that brick shall bear the name of its maker, or of the originator or architect of some erection famed in sacred and profane history? What is there that calls forth greater interest than the pyramids of Egypt, the remains of Thebes, the "dead cities" just named, or the remains of ancient Greece and Rome? We contemptuously pity that man who, with his Horace, Juvenal, Herodotus, Xenophon, and other Greek and Roman authors in hand, cannot feel an enthusiasm when he visits the scenes where some of the greatest dramas of human life have been played—where the remains of ancient kingdoms, in their architecture, their domestic utensils (as at Athens, Corinth, Rome, Pompeii, Herculaneum, &c.), may be seen, admired, and studied.

Mr. Barlow remarks—"It has been questioned which of the two sister arts—brick-making or pottery—is the most ancient; although it is generally admitted that they are both amongst the earliest efforts of human ingenuity. Bricks are frequently mentioned in the early history of the Old Testament, as is also the potter's wheel. We should, however, be inclined, from the simple process in the one case, compared with the artificial means necessary in the other, to decide in favour of brick-making. The walls of Babylon were, unquestionably, built with brick; and unburned bricks were employed in many of the ancient buildings of Egypt. Several, indeed, of the pyramids, and other edifices, are of stone; but Pocock describes a pyramid of unburned bricks, called 'Kloube-el-Menshich'—the brick of Menshich, brought from a village near, called 'Menshich Dashoud.' It was, doubtless, built near the plain on account of the bricks, which seem to be made of the earth of the Nile, being of a black sandy nature with some pebbles and shells in them. It is mixed up with chopped straw; in order to bind the clay together; (see Exodus, c. v., v. 16—"There is no straw given to thy servants," &c., and context, by which the ancient use of straw in brick-making is shown), as the inhabitants now make unburned bricks in Egypt, and many other eastern parts, which are used very much in their buildings. 'I found,' says the author, 'some of these bricks thirteen and a-half inches long, six and a-half inches broad, and four inches thick; and others fifteen inches long, seven inches broad, and four and three-quarter inches thick. I observed, on the north side, that the bricks were laid lengthwise, from north to south, but not everywhere in that direction; however, I particularly took notice that they were not laid so as to bind one another.'" We need scarcely say, that the researches of Sir H. Rawlinson and Sir A. Layard in the East, have brought together some most interesting facts in relation to the nature of the brick used thousands of years ago, and the mode of constructing all kinds of edifices in the days of Nineveh and Babylon; and we cannot do better than refer our readers to the published works of those eminent antiquarians, in respect to further and most reliable information on this most interesting subject.

In many eastern countries the old method of sun-drying bricks is still pursued. "In Persia, the bricks are both sun-dried and baked. The sun-burnt bricks are made in wooden moulds, about eight inches long, six wide, and two and a-half deep. The earth is tempered by treading with the feet, and is mixed with finely-cut straw. While the bricks are in the mould, they are dipped into a vessel of water mixed with chopped straw, and then smoothed by the hand; the moulds are then removed, and in about three hours the bricks have attained sufficient consistency to be handled, when they are placed in rows one over another, to become thoroughly dry. The baked bricks are made of earth and ashes." Dr. Kennedy, in his *Campaign of the Indies*, says—"Nothing I have ever seen has at all equalled the perfection of the early brick-making, which is shown in the bricks to be found in these ruins (those of ancient tombs near Tatta); the most beautifully chiselled stone could not surpass the

sharpness of edge and angle, and accuracy of form; whilst the substance was so perfectly homogeneous, and skillfully burned, that each brick had a metallic ring (when struck with any hard substance), and fractured with a clear surface like breaking free-stone. I will not question the possibility of manufacturing such bricks in England; but I must doubt whether such perfect work has ever been attempted."

In reference to the bricks of later times than the most ancient to which we have referred, it may be remarked, that the Greeks and Romans, whilst knowing the art of brick-burning, yet employed unburnt bricks. It has been supposed that the Greeks did not use bricks for building purposes until after they were subdued by the Romans; but this is an uncertain question. Vitruvius says, in respect to making unburnt bricks—"They should not be made of stony, sandy, or gravelly loam, for such kind of earth renders them heavy; and upon being wetted with rain, after being laid in the wall, they swell and dissolve; and the straw which is put in them does not adhere on account of their roughness. The earth of which they are formed should be chalky, white or red. They should be made in spring or autumn, as being the best time for drying; for the intense heat of summer parches the outside before the inside is dry; which afterwards, drying in the building, causes them to shrink and break. They are best when made two years before they are used, as they cannot be sufficiently dry in less time. If they are used when newly made and moist, the plaster work which is laid on them will remain firm and stiff; but the bricks shrink, and consequently, not preserving the same height with the incrustation, it is by such contraction loosened and separated. At Utica, therefore, the law allowed no bricks to be used before they had lain to dry for five years."

In respect to the history of the allied art of pottery, our museums of the present day present a large number of specimens of ancient art, that are not only interesting, but highly instructive; indeed, often affording models for modern patterns. The most beautiful form of a perfectly plain, unornamented vase that we have yet seen, was copied by Messrs. Bell, of Glasgow (the eminent potters near that city). It had not the slightest decoration, but was a reproduction of the original, as got from the ruins of Pompeii. Its beauty, in fact, consisted in the elegance of its simplicity.

It would be impossible for us here to describe even a fraction of the numerous antique specimens that have been discovered, and are now stored in various museums. In the British Museum, London, the inquirer interested in such matters cannot fail to find a large fund for study; many, and indeed most, of the articles being in an admirable state of preservation. The following engravings illustrate some very interesting vessels of pottery. Fig. 36 shows some ancient Egyptian porcelain vessels. Fig. 37 is a Pompeian drinking-vessel; and Fig. 39 an earthern cup from Pompeii. In Fig. 40, an oriental ewer and basin are illustrated.

We need not remind our readers of that splendid specimen of antiquity, known as the Warwick Vase, which was dug up from the ruins of Hadrian's Villa, at Tivoli, and sent to England, in 1774, by Sir William Hamilton. It is represented in Fig. 38.

Fig. 36.—Ancient Egyptian Porcelain Vessels.

Fig. 37.—Pompeian Drinking-vessel.

Of equal celebrity is the well-known Portland or Barberini Vase. It shows that ancient taste was of the most refined character as applied to the manufacture of pottery, and glass vessels generally. The Warwick Vase is formed of white marble, and has been considered as the work of the celebrated Lysippus, a Greek sculptor, who flourished in the time of Alexander.

Fig. 38.—The Warwick Vase.

It has a capacity of 163 gallons; and the exterior is beautifully adorned with bas-relievo sculpture.

The Portland Vase we have here named simply to show the skill at ornamentation which the Greeks possessed. It was discovered in the middle of the sixteenth century, in a sarcophagus within the monument of Alexander Severus, the Roman emperor, about two miles and a-half from Rome. It fell into the hands of Sir William Hamilton, and was purchased by the Duke of Portland; hence one of the names by which it is known, as it was called the Barberini Vase, from having been in the possession for some time of a Roman family of that name. It was lent to the British Museum, when, some years ago, it was broken by a fanatic, whom, unfortunately, our laws could not give just punishment to, for the wilful destruction of one of the most beautiful specimens of ancient art. It was, however, put together again so skilfully, that the injury to it became

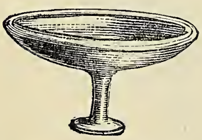


Fig. 39.—Earthen Cup, from Pompeii.

Fig. 40.—Oriental Ewer and Basin.

Fig. 41.—Portland or Barberini Vase, in the British Museum.

barely apparent. Its description is as follows :—" Its dimensions are small, the height being only about ten inches, and its diameter at the broadest part only six inches. But its shape is very elegant ; the swell of the lower and central portion diminishes gradually to a narrow neck, and that gracefully again opening towards the lip, like an unfolding flower. It is supported by two handles inserted at the concave or narrow part. The material is a dark but transparent blue substance—undoubtedly a sort of vitrified paste or glass, although long supposed to be some species of stone. Upon this, the figures, formed of a delicate opaque white substance, are laid in bas-relief ; and so firmly are they united to the ground upon which they are thus fixed, that they seem rather to have grown out of it, and to have been part of itself, than to be fastened on by art. It is difficult, indeed, to conceive by what process the union between the two substances was effected. They must, of course, have been brought into contact when both were in a soft state, and then, apparently, they were run together by heat. If the action of fire, however, was employed for this purpose, it has not injured the finest line of any of the figures. Every stroke is as sharp and unbroken as in the most finished delineation that ever were drawn by the pencil or cut by the graver, or struck from the die." It is represented in Fig. 41.

In the British Museum are several specimens of Etruscan art in pottery. To our modern ideas, the style of ornamentation is too formal ; but the shape or contour of many of the specimens in our national collection, is often very elegant. In the following cut (Fig. 42), an Etruscan vase is represented.

Fig. 42.—An Etruscan Vase.

The amphora, or ancient form of wine-vessel, is frequently mentioned by old writers. It was an earthern vessel, supposed to have been used to contain the fermented juice of the grape—just, in fact, answering the purpose of the modern wine-bottle for storing that beverage. An earthern amphora, of the kind here alluded to, is represented in the following cut (Fig. 43). It may be remarked as by no means unlike the modern oil-vessels of Italy, except that the latter have not the pointed end or apex of the amphora. From the frequent representations of this vessel in Egyptian relief, paintings, &c., it is considered that they first used the vessel, and that it was subsequently copied by the Greeks, Romans, and other peoples.

In our own country specimens of Roman pottery are constantly being found, that show the art to have made great progress even 2,000 years ago. On one occasion we "assisted" at the opening of a kind of tumulus, that must have been the burying-place of Roman soldiery a little after the time of Cæsar, or about 1,900 years ago. Many vases and urns were discovered, some of which were of beautiful form or design. According to Mr. Porter—" We learn, on the authority of Vitruvius, who wrote in the Augustan age, that the Romans then made their water-pipes of clay. This people, who introduced a knowledge of the useful arts practised by themselves wherever their conquests were extended, established potteries in England, where many other articles similar to water-pipes were made. Some of these, about a century ago, were dug up in Hyde Park ; they were found to be of two inches in thickness, and were fairly joined together with common mortar mixed with oil. It has been asserted that the ancient Britons were in the habit of making pottery before the invasion of this country by the Romans ; and, in support of this belief, is brought the fact that urns of earthenware have been taken from barrows in different parts of the kingdom. On the other hand, the concurring

testimony of various writers gives reason for supposing that our ancestors were, in those days, supplied with such articles by the Venetians. Vestiges of considerable Roman potteries are discernible in many parts of this island, and particularly in Staffordshire, on the site of the great potteries which have so long been carried on in that county. In sinking pits for various purposes, remains of Roman potteries have occasionally been discovered there, at a considerable depth below the surface. Governor Pownall relates that, in 1778, the men employed in fishing at the back of Margate sands, in the Queen's Channel, frequently drew up, in their nets, some coarse and rudely-formed earthern vessels; and that it was common to find such pans in the cottages of these fishermen. It was for some time believed that a Roman vessel, freighted with pottery, had been wrecked there; but, on more particularly examining the spot, called by the fishermen 'Pudding-pan Sand,' some Roman bricks were also discovered, cemented together so as to prove that they formed part of some building. Further researches showed, that in Ptolemy's second book of *Geography*, an island was designated as existing in the immediate vicinity. Such pans as were recovered in a sound state were of coarse materials, and rude workmanship; many having, very neatly impressed on them, the name of Attilianus; but fragments of a finer and more fragile description of pottery were likewise brought to the surface; and little doubt remains, that during the time of the Roman ascendancy in England, a pottery was established here, upon an island which has long since disappeared; and that the person whose name has been thus singularly preserved, was engaged in its management."

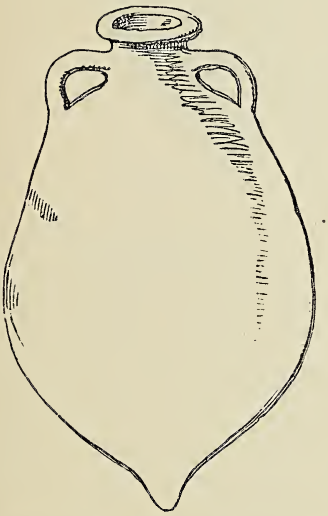


Fig. 43.—An Earthern Amphora.

With specimens of Roman mosaic work, in the shape of tiles, most of our readers will, doubtless, be familiar. A fine one of the kind was brought to light at the corner of Threadneedle Street, near the Royal Exchange, London, some years ago, and many beautiful relics of this kind of work have been preserved.

But although the Egyptians, Greeks, and Romans had thus made early progress in the potter's art (and we have not named the Israelites as being contemporary with all these at different periods of history), still ruder and uncivilised nations were not behind, as the remains found in Peru, Mexico, and Central America, testify.

Some very singular specimens of ancient pottery have been found in various parts of North and South America. Fig. 44 represents a grotesque Peruvian jar; and the succeeding cut (Fig. 45), one of much less pretension to art. By Fig. 46 we are somewhat reminded of the Etruscan style of ornamentation, already illustrated at page lx, *ante*, by Fig. 42. It is extremely singular that so near an approach to similarity of style should be made, in ancient Peru, to the Grecian or Etruscan style, considering that the two countries are separated by what, at the time this specimen of pottery was made, must have been considered as impassable oceans. Even at the present day, with all our modern appliances, at least two month's time would be required to hold direct communication between Greece or Italy and Peru; and, at the early times to which we have referred, such a communication, if at all possible, must have taken an age to accomplish. In fact, modern human reason must necessarily conclude, at that period, any such traverse of space to have been utterly impossible to any one man in an ordinary lifetime. How, then, can we suppose otherwise than that, by means of some accident, and not by design, the arts were transferred to the "New Continent," and found a congenial soil for their growth in that unity of mind that characterises man arisen from one origin; or, consistent with this, we may suppose that distant, straggled races of men, still keeping innate the early principles of mental progress, gradually develop them under favourable conditions of mental and æsthetic expansion—seed long latent, but at last bringing forth abundant fruit.

We quote the following interesting account of what has been discovered in respect to the early pottery art of the New World. It can be no matter of surprise that Egypt, Greece, Rome, China, India, and other of the Old World countries, have made gradual and constant progress,

not only in pottery, but in the sister arts of all kinds; for it is a comparatively easy task to trace that progress for scarcely less than 5,000 years. But our knowledge of the whole continent of America has not attained a period of 400 years; and hence anything that can be gleaned respecting it, especially in relation to our subject in hand, cannot fail to be of deep interest.

Fig. 44.—Peruvian Jar.

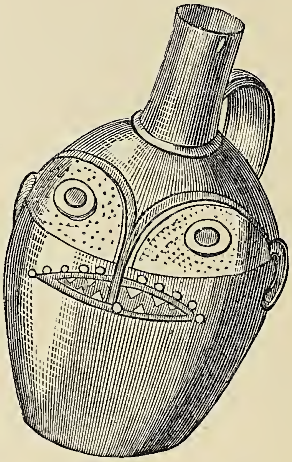


Fig. 45.—Peruvian Jar.

The authority to which we now refer, states, that Mr. Stephens, a talented observer, was sent, some years ago, on a political mission, by the Government of the United States, to Central America; and spent his spare time in exploring the ruins of six or eight cities, whose history is a perfect blank, but whose buildings showed evident marks of a state of art and civilisation very different indeed from that exhibited by the Indian inhabitants of the same district at the present day. Since his explorations others have followed in the same track, and have found many interesting results. In the course of Mr. Stephens' explorations, he repeatedly met with terra-cottas and specimens of pottery, showing that these were among the branches of art cultivated by the former dwellers of these cities. Some of the specimens were deposited in a remarkable way. For instance, in one mass of ruins there were several holes in the ground, leading to subterranean chambers; and one of these openings Mr. Stephens determined to explore. "The opening was a circular hole, eighteen inches in diameter, The throat consisted of five layers of stones, a yard deep, to a stratum of solid rock. As it was all dark beneath, before descending, in order to guard against the effects of impure air, we let down a candle, which soon touched the bottom. The only way of descending was to tie a rope round the body, and be lowered by the Indians. In this way I was let down.

Fig. 46.—Peruvian Jar.

and almost before my head had passed through the hole, my feet touched the top of a heap of rubbish, high, directly under the hole, and falling off at the sides. Clambering down it, I found myself in a round chamber, so filled with rubbish, that I could not stand upright. With a candle in my hand, I crawled all round on my hands and knees. The chamber was in the shape of a dome, and had been coated with plaster, most of which had fallen, and now encumbered the ground. The depth could not be ascertained without clearing out the interior. In groping about I found pieces of broken pottery, and a vase of terra-cotta, about one foot in diameter, of good workmanship, and having a coat of enamel, which, though not worn off, had lost some of its brightness. It had three feet, each about an inch high, one of which was broken. In other respects it was entire." In some of the other subterranean chambers that Mr. Stephens explored, the openings were so small, that, to use his own expression, he had to undergo a "severe rasping" against the sides of the opening before his Indians could pull him out. In some instances he found vases and pottery, but not in all; most of the buildings, or ruins of buildings, were found on or near elevated mounds; and it was near these mounds that Mr. Stephens made his search. He gives an engraving of an elegant vase near a place called Ticul. On one side of this vase is a border of hieroglyphics, with smaller lines running to the bottom; and on the other is sculptured a figure, with a head-dress formed of a plume of feathers, and the hand held out in rather a stiff position. The vase is four and a-half inches high by five in diameter. At another spot, in a subterranean hollow, where a skeleton was found, was also discovered a large vase of rude pottery, resembling very much the *cantaro* used by the Indians, at the present day, as a water jar. It had a rough flat stone lying over the mouth, so as to exclude the earth; and a small hole worn in one side of the bottom, through which the liquid or pulverised substances could have escaped. . . . . At the foot of one of the explored ruins was a vault, faced with cut stone, in which were found a collection of bones and a terra-cotta vase. The vault was not big enough to contain the body of a man if extended, and the bones must have been separated before they were placed there. Mr. Stephens made a bargain with the owner of the ground, by the terms of which they agreed to explore together, and that Mr. Stephens should have the right to all the curiosities found; while the other was to have all the hidden treasure, of the existence of which reports had been rumoured. The treasure was not forthcoming, for none could be found; but Mr. Stephens met with two vases. One of these was entire, and was graceful in design, well made, and had a good polish on its surface; the other was broken, and though more complicated in form, had no polish on its surface. Another vase, previously found on the same spot, was a basin-shaped vessel, about twelve inches in diameter, supported on three feet, and ornamented and polished at the surface.

We have thus imperfectly traced some of the most interesting portions of the ancient history of brick and pottery ware, so far as information in any way to be relied on, and evidently in part fabulous, is known. It is impossible to point to any artistic occupation of mankind in which so little change in material, mode of manufacture, design, and general progress has been made in the course of thousands of years. Most articles of domestic use in pottery have either been copied, more or less, from the products of remote ages, or in a great measure resemble them. As already pointed out in regard to design, the modern system of even our best ware only differs in elegance and perfection of execution, but not in absolute character, from that which characterised Egypt, India, China, Greece, and Rome twenty or thirty centuries ago. But, in respect to material, this want of change is at once explained, for none other than the generically termed "potter's clay" could answer the requirements of the art. The character of the product, however, varied with the nature of the material.

We shall not here enter on the history of the modern art of brick and pottery as carried on in our country and abroad, as this subject will be fully dealt with in a future chapter. We next turn briefly, to the history of the glass manufacture, as one of only next importance to that of pottery.

Amongst all manufactures that have been advanced of late years, through various causes, that of glass is most remarkable. Formerly, when, through fiscal regulations, the hands of the manufactures were literally tied; when none of the glass-house operations could be carried on, except under the eye of the exciseman; and when the duty was really enormous (for the glass on each re-melting was again chargeable), it is no matter of surprise that the progress of the art was slow, and its products exceedingly expensive. Many of our readers will remember the great cost of glass for domestic vessels, equally with that for making windows, whether as

crown or plate-glass. Now, however, the trade being freed from the fetters that long bound it, the price of all glass articles is enormously reduced, so as to put many of them into competition for cheapness with even the lower kinds of pottery. Instead of the ugly little panes that are now only to be seen in some obscure street, our house and shop-windows are fitted with large plates that admit abundance of light—no mean adjunct to health—and of the highest importance to the tradesman in the display of his goods. Science has equally benefited; for in our younger days, the high price of glass vessels, such as retorts, jars, and other chemical utensils, actually forbade the pursuit of experimental science, except by those whose means were large, or who had access to the apparatus of a public institution. Indeed, the abolition of duty on glass and paper, may be taken as pointing out the enlightened conditions of our time; for the existence of that duty on the materials named, was neither more nor less than a severe tax on air, light, all trades, health and knowledge.

The properties of glass are such as to recommend it to universal use. Its transparency, whilst giving beauty to all kinds of vessels, at the same time gives the power of excluding air and moisture from our dwellings, whilst little light is shut out. By this same transparency the astronomer is enabled to penetrate into regions of space that the power of man's mind can neither accurately express, measure, nor form a just conception of. On the other hand, the microscope has opened out worlds of wonder, just as astonishing and perfect in their character as the planets or stars of the astronomer. By aid of glass, indeed, we can study the two extremities of creation—the great and the small—the immense and the most minute.

Another advantage of glass is its indestructibility. At p. lviii *ante*, we have given a lengthened description of the Barberini or Portland Vase, which, although now above 1,800 years old, preserves all the freshness of its youth. A good glass is not perceptibly acted on by any chemical agent met with in nature or in domestic life; and, indeed, this property of indestructibility recommends glass as the chief material for making the vessels of the practical chemist, who, with the exception of the action of two or three compounds, reckons that glass undergoes, practically, no change in the course of experimental inquiry.

A matter of interest, in an ornamental point of view, is the readiness with which glass receives colour from all suitable agents, and its power of permanently retaining such colour. Hence the great variety of ornamental coloured vessels, the beautiful art of glass staining, and other applications of this property of colour, too numerous to detail.

A very important quality is its capability of receiving and retaining a polished surface. Hence its value in forming the material for constructing mirrors that infinitely surpass the best metal mirrors of the ancients. It is also readily worked at a comparatively moderate temperature, and can therefore be blown, pressed, rolled, or moulded into any conceivable form. Allowed to regain a solid condition, it can be "cut" into beautiful forms for all kinds of purposes. And at last, when its forms are destroyed by inattention to its brittleness, it can be returned to the melting crucible, to assume new shapes, and again enter into useful or ornamental employ.

In the preceding remarks on pottery, we took occasion to point out how ancient that art is. Less is known in respect to the earliest history of the glass manufacture; but there is no doubt that the Tyrians understood it, and established glass-houses. According to Pliny, "some merchants, being driven by a storm at sea to the mouth of the river Belus, were obliged, during the time they were detained there, to dress their victuals by kindling a fire on the sand, where the herb kali grew in great abundance, and that the salts of this plant, on being reduced to ashes, incorporated with the sand or with stones fit for vitrification, and thus produced glass." Like many accounts of the early stage of the arts, this may contain much that is fabulous; but certainly the sand, in the neighbourhood referred to, was eminently fitted for glass-making, and was at the command of a nation then the most enterprising of any in respect to the arts, commerce, and foreign trade by shipping.

The discovering of glass beads in the tombs of Egypt and Thebes, evidences that the art of making glass was known to the Egyptians. Singular to say, the Esquimaux possess beads of similar colour and size, made of glass, at the present day—a circumstance that may be considered in connection with the remarks made at p. lxi *ante*, in relation to the art of pottery as carried on in early times by the inhabitants of Central America, Peru, &c.

According to Barlow and other authorities, "the glass-houses of Alexandria were celebrated, amongst the ancients, for the skill and ingenuity of their workmen; and from these, the Romans,

who did not acquire a knowledge of the art till a later period, procured all their glass ware. Strabo relates, that a glass-maker of Alexandria informed him, that an earth was found in Egypt, without which the valuable coloured glass could not be made; and it is stated by Pliny, that, in the reign of Tiberius, a Roman artist had his house demolished for making glass malleable; and that, in consequence of this discovery, glass came into such general use as to supersede cups of gold and silver; and the glass-makers became so important, that a street was assigned for them in the first reign of the city."

That the Chinese should have been early acquainted with glass-making, might be expected from their known character for ingenuity in branches of art that, at the same period, were unknown in more westerly nations. They succeeded admirably in producing glass imitations of precious stones, made into vases, &c., that commanded enormous prices. This article was of white, blue, and other colours, and was a thin coloured glass. A specimen of this imitation may be seen in the British Museum. It resembles enamel, has a bluish-white colour, and, in form and size, resembles a modern snuff-box.

In the British Museum there are various specimens of ancient glass, especially as collected from Herculaneum and Pompeii. The annexed cut (Fig. 47) illustrates two beautiful glasses found in the ruins of Pompeii. In more modern times, Venice became distinguished for the excellence of its glass manufacture, but especially in the ornamental departments of the art.

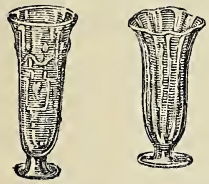


Fig. 47.—Glass Vessels, from Pompeii.

In our own country, the Druids understood the art of making glass beads, rings, &c. "The glass amulets made by them are about half as wide as our finger rings, but much thicker; they are usually of a green colour; but some are blue, and others curiously variegated with waves of blue, red, and white." Specimens of these ancient curiosities will be found in the British Museum.

It was long before the art of making flat glass, suitable for glazing windows, was achieved; and the first glass-houses of any importance were erected in Crutched Friars and in the Strand, London, about the middle of the sixteenth century. Eventually the use of pit coal was substituted for that of wood, which had been previously employed; and that could scarcely have afforded such a sufficient steady heat as is required in melting the constituents of glass, and still less of keeping the melted "metal" at an even temperature for working. At this period our glass manufacture was far below that of foreign countries. But the second Duke of Buckingham contributed much to stimulate the trade, by inducing some Venetian workmen to come over to England; and he established, in 1670, a plate-glass factory at Lambeth. This manufacture had previously been commenced in France, where, about twenty years afterwards, the celebrated St. Gobain factory was established. About 1773, a company was formed in England for the manufacture of plate-glass. Gradually, the investment of capital in the glass trade increased, and many establishments were formed in London, Newcastle-upon-Tyne, Lancashire, &c. The aid of chemistry was called in to each branch of the art, and thus it has gradually arrived at the perfection which it now enjoys. In the race between different countries, our own has long been most advanced, and the British flint and plate-glass, but especially the former, is the best that is now manufactured.

We may next turn—in briefly describing the rise and progress of some of our most useful arts—to that of the various means of *Artificial Illumination*. One of the earliest requirements of humanity, even in the countries which first became the abiding-places of our race, was that of artificial light, to illumine the darkness, and also to kindle fires used for preparing food.

Judging by modern methods, in savage countries, there is little doubt that friction of hard and dry surfaces of wood was at first resorted to for the purpose of "getting a light," as that operation is conventionally termed at the present day. In the northern regions of North America, this plan is still adopted by the Esquimaux, as it also is in many of the South Sea Islands, Africa, and other uncivilised countries; the extreme drying effect of either great heat or cold answering precisely the same purpose—that of making the wood readily ignitable by friction. Amongst the Esquimaux, the method of general use is that of rubbing quickly a piece of wood somewhat of the shape of a paste rolling-pin, with its pointed end in a hole in another piece of hard, dry wood. The friction thus created is sufficient to ignite, by sparks, some dry moss, which serves, at the same time, with a few sticks, for "tinder" and fuel.

Some of our readers will remember the old-fashioned method of obtaining light by means of the flint, steel, tinder-box, and sulphur-match, now long disused, and substituted by the lucifer-match. By such rude means a light was obtained; each stroke of the flint causing a minute portion of the steel to be broken off, which, by the friction so generated, ignited, and, falling on the tinder, produced a red smouldering mass, from which a light was obtained by dipping into it the sulphur-match.

Simultaneous, but of rarer use, was that of dipping wooden matches, coated at their end with a mixture of chlorate of potass and sugar, into strong sulphuric acid, or oil of vitriol, by which, so long as the acid retained its strength, an instantaneous light was afforded. But, unfortunately for the permanent value of such an arrangement, the acid has a strong attraction for the aqueous vapour, or moisture, in the atmosphere, and consequently, its virtue was speedily lost. There was, also, the constant danger of spilling the acid on articles of dress, &c., by which not only their colours, but the texture was destroyed; and, added to this, was the risk of poisoning, owing to the corrosive action of the acid. For these reasons the flint and steel became greatly preferred, and of constant use; and the sale of tinder was a recognised object of retail trade amongst the ironmongers of all market towns, although the good housewife economised this cause of expense by making her own tinder out of old rags of no other possible use.

It seems strange, in our days, to understand how our forefathers or mothers could, for so many years, have been contented with the use of flints to obtain light for the household, and to ignite the powder of sporting and other weapons of destruction; yet the use of flints was so extensive as, at that time, to have become an important article of trade, and almost, we may say, of mining. Formerly, at Brandon in Suffolk, the flint for such purposes was obtained, although recourse was had to the extensive deposits of flint in the chalk of northern and eastern Kent. At Brandon, shafts were regularly sunk, as in mining for metal: at different depths regular beds of flint were discovered, which being in general horizontal, were mined out. The flint, being raised to the surface, was dexterously shaped, either for gun or house-flints, by means of steel hammers and chisels—a work requiring considerable experience and skill to perform effectually and without loss.

Among what we call philosophical instruments used for getting a light was Dobereiner's lamp, which was so constructed that, by an internal arrangement, hydrogen gas was produced, which, by the opening a tap, impinged on a piece of spongy platinum. Owing to a peculiar property which this metal has of condensing hydrogen, with oxygen in this case found in the external atmosphere, sufficient amount of heat is produced to inflame the hydrogen, which, consequently, can ignite an ordinary match, although, as thus produced, giving itself no available amount of light. Ingenious as this arrangement is, it was quite unfit for use generally, more especially in the domestic circle, and it was consequently confined to mere lecture-table illustration of the powers of spongy platinum.

The greatest advance that was made in affording the means of getting a light, was in the invention of the "lucifer match." The first matches of this kind were ignited by pulling the tipped end of the flat match between two pieces of sand-paper; or, rather, one piece bent double, and held between the thumb and finger of one hand, whilst the match was drawn by the other. These lucifers, however, had the inconvenience of not striking a light unless this peculiar form of sand-paper was at hand. Subsequently, phosphorus, which readily ignites by friction on any hard, rough body, became an essential element of the match, together with chlorate of potash and sulphur; and, by a series of graduated improvements, the individual steps of which we cannot here detail, the match of the present day was arrived at in its various forms and cheapness.

There are few instances, in the entire range of manufactures, in which we can find so great social importance depend on an object so trifling, apparently, as the modern match; and yet, in our households, and in other circumstances that we need not allude specially to—for our readers can readily supply the hiatus—the match is an essential of civilised existence throughout the world. As producing means of employment, its statistics are, when arrived at, simply astonishing; millions upon millions of this little agent being cast off annually at scores of manufactories, and ship-loads of timber being necessary to supply the material for this unpretending article. But we may add, that the demand for phosphorus, sulphur, chlorate of potass, and other chemical ingredients required, have had also an extended influence on other

branches of trade, but especially on those chemical manufactures where such articles are produced. Another matter of surprise is found, not only in the abundance in which such articles are afforded, but also their cheapness. In our earlier days phosphorus and chlorate of potass were sold at, comparatively speaking, fabulous prices; while now they have become amongst the cheapest of chemical products. It may, therefore, be safely asserted, that even in the common lucifer, chemistry has done much for mankind.

Having thus hastily sketched out the history of "getting a light," we may next turn to the means of maintaining it; or, more plainly, the various methods of artificial illumination that have been adopted at different periods.

There can be scarcely a doubt that, in the earlier stage of man's history, the wood fire was, at the same time, the source of light for night illumination, and that of heat for cooking food. Whether Prometheus was really the first man that stole fire from heaven (and by some sapient individuals it has been suggested that he erected lightning conductors for the purpose) we will not pretend to determine. One thing, however, is certain, that wood, of all other substances, was the most likely material that could be employed at first for producing and propagating artificially afforded light and heat. In most countries, except in the Arctic and Antarctic regions, trees abound that contain, besides the woody matter, resinous and, occasionally, oil-like secretions admirably adapted for light-giving purposes. Of the early history of artificial illumination, as illustrated by modern usage, we have met with some interesting instances in the north and west highlands of Scotland, where in many parts an almost primitive state of existence still survives the shock of civilisation, and where poverty of the most extreme kind frequently, in a measure, reduces the inhabitants almost to a state of nature in its earliest forms. There a stone at one end of the hut, often built of turf, serves as a fire-place, on which is heaped twigs of the fir, commonly very abundant in those parts. After the flame ceases, the burning embers shed, for some time, a lurid red light, sufficient for all the wants of these unpretending little households. On a visitor making his appearance, a few more dried sticks thrown on, at once increases the light and heat sufficient to give a kind of snugness, and even comfort, to the apartment, if such hovels can be properly dignified with that title. A glance at such a scene, and in the wild country to which we are alluding, at once brings the mind back to days in which historians describe our country as but just emerging from barbarism. We are reminded of the curfew bell, and, with it, of all the legends, tales, and traditions, that give a romantic tinge to the history of our own nation.

When candles and lamps became first employed it is impossible to determine; but that they are of very ancient date is beyond question; for they are frequently named in sacred and profane history. It is not certain, however, that, at times, the word expressing each may not have been indifferently translated for both. At the present day, some savage tribes use berries strung on a stick, and burn them somewhat after the form of a candle—a method evidently self-originated, and not the result of imitating civilised fashion.

According to Pliny, candles were in use in the days of Numa Pompilius, or at a period of about seven hundred years antecedent to the Christian era; for he states that the lost books of Numa were tied round in every way with candles, after the manner of the cere, or wax-cloth. This leads us to suppose that the method of using a wick, surrounded by some fatty substance, was even at that early date, a plan of artificial illumination. In the days of Pliny, it is evident, according to his own account, that what are now termed rushlights were in ordinary use. But in such comparatively civilised times, we need not be surprised that something in the form of a candle should have been invented; for in the ordinary operation of cooking, the fact that the fat of animals is readily combustible, especially if in contact with vegetable matter, as a stick or twig, quite sufficient would be seen to suggest some stable form in which that could be put to use as a permanent illuminating agent.

There is scarcely a doubt that torches, of a similar kind to those now used—that is, some vegetable matter steeped in resin or pitch—were early known; and it has been suggested that the lamps of the Gideonites were of a torch kind, having cloth imbued with oil, twisted round a solid central substance, of use as a kind of holder. The remains of Pompeii have, fortunately, placed us in a favourable position for judging of the method of artificial illumination in those days, when Roman civilisation had arrived at its zenith. Some of the lamps and candelabra then in use were most artistic in their construction, and might, indeed, serve as models for modern imitation. The lamps were of various shapes, many of the hand-kind exactly resembling

the modern teapot, the wick being supposed to be inserted in the spout, whilst the oil was supplied through what now constitutes the opening covered by the lid of the present article. Fig. 48 represents a bronze lamp and stand found among the ruins of Pompeii.

In some instances, the oil-lamps were so made as to be suspended from over-head, much resembling the manner in which the modern gaseliers are fixed in our ceilings. The British Museum contains several specimens of such lamps.

Fig. 48.—Bronze Lamp and Stand, found at Pompeii.

In respect to the candelabra of the Romans, it would seem that they took the place of our candlesticks. The author of *Pompeii* remarks—"They, in their original and simple form, were probably mere reeds, or straight sticks, fixed upon a foot by peasants, to raise their light to a convenient height; at least, such a theory of their origin is agreeable to what we are told of the rustic manners of the early Romans; and it is, in some degree, countenanced by the fashion in which many of the ancient candelabra are made. Sometimes the stem is represented as throwing out buds; sometimes it is a stick, the side branches of which have been roughly lopped, leaving projections where they grew. Sometimes it is in the likeness of a reed or cane, the stalk being divided into joints. Most of those which have been found in the buried cities are of bronze; some few are of iron; in their general plan and appearance there is a great resemblance, though the details of the ornaments admit of infinite variety. All stand on three feet, usually griffin's or lion's claws, which support a light shaft, plain or fluted, according to the fancy of the maker. The whole supports either a plinth large enough for a lamp to stand on, or a socket to receive a wax candle, which the Romans used sometimes, instead of oil, in lighting their rooms. Some of them have a sliding shaft like that of a music stand, by which the light may be raised or lowered at pleasure."

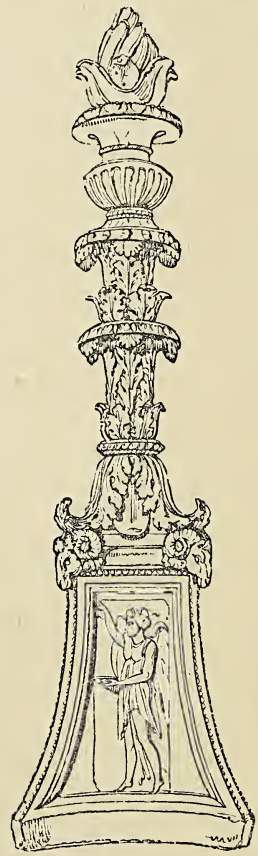


Fig. 49.—Roman Candelabrum.

Fig. 49 represents a Roman candelabrum of elegant design. It is in the Townley collection of the British Museum, and made of marble. It is rather more than four feet in height, and is profusely and elegantly decorated.

It would be exceedingly interesting, if space had permitted, to have extended our remarks and descriptions to the modes of artificial illumination adopted in other countries than those already alluded to, and in ancient times. But generally, this would be but a partial repetition of what has already been stated, for great similarity is discovered in lamps, &c., of the Egyptians, Persia, Arabia, and other Asiatic countries, that most probably had constant communication with Greece and Rome; and hence suggested to, or received improvements therefrom. The following cut represents various forms of Egyptian lamps, which much resemble the Roman style already described and illustrated. (See Fig. 50).

As to the material used as fuel for the lamps, it was, doubtless, in most cases, at first vegetable oils, obtained by heat and compression—the oil of the olive being mostly used in Rome. Animal fats, however, were in use; and as there is nothing new under the sun, it will not surprise our readers to find that a species of petroleum was employed in Sicily, supplied by a spring in Agrigentum, that afforded it much

after the fashion of the more modern oil-wells of the United States of America. The wick was, most probably, made of flax, that being an exceedingly abundant and common material amongst the ancient Greeks and Romans.

In our own islands, candles were in early, and perhaps sole use, for no seed was then grown in this country that could afford lamp oil. The use of wax in the form of candles was known to Alfred; and he had them made in such a manner, that, in burning, they served to indicate the progress of time. The ordinary wood fire was, most probably, the means of illumination of houses of the poorer classes for a long time after; hence the curfew of William I., by which all lights in houses were directed to be extinguished at a certain time, in order that no light might assist the treasonable machinations against that usurper, who, like many before and since his day, conceived that he could extinguish both mind and patriotism by placing them in darkness.

So far we have chiefly noticed early artificial illumination in respect to the interior of houses, &c.; and it may seem surprising that even ancient Rome was a stranger to any regular mode

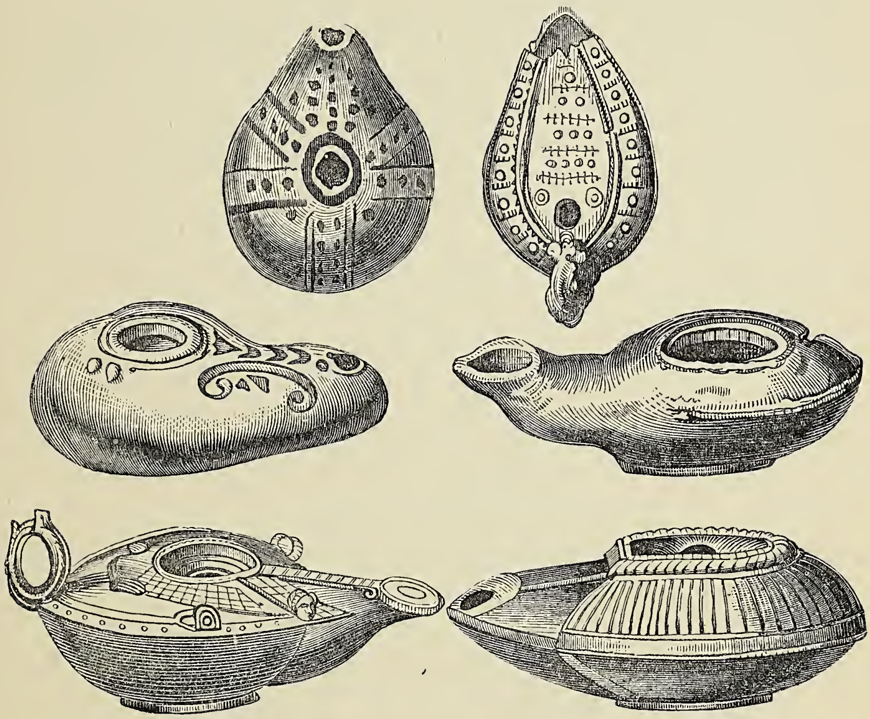


Fig. 50.—Egyptian Lamps.

of public street-lighting. On this subject, a high authority in everything pertaining to artificial light, has remarked:—" We are told that the streets of Rome, even in her palmiest days, rarely exhibited more than one or two lanterns, which were suspended over the baths, and other places of public resort. Now and then they were illuminated for a festival; and sometimes the forum was lighted up for a midnight exhibition; but with these few exceptions the city was a city of darkness. In the fourth century, the streets of Antioch and Edessa were furnished with public lamps. Libanius, in his panegyric of the former, says:—The light of the sun is succeeded by other lights, which are far superior to the lamps lighted by the Egyptians on the festival of Minerva and Sais. The night, with us, differs from the day only in the appearance of the light: and with regard to labour and employment, everything goes on well, for some work continually, while others laugh and amuse themselves with singing. This fact is confirmed by Jerome, who tells us of a serious dispute that was maintained for some hours in the streets of Antioch, between a disciple of Lucifer and one of the orthodox: he says that the dispute was kept up until the

streets were lighted, and then the disputants spat in each other's face, and retired. In his history of Stylites, we are informed that Eulogius, the governor of Edessa, in Syria, ordered lamps to be kept burning in the streets during the night; and that he employed for that purpose a part of the oil which was before given to the churches and monasteries. It is worthy of notice, however, that public illuminations, either on account of religious festivals, or general rejoicings, were very common with the ancients, and are of great antiquity. Herodotus states that the Egyptians had a festival of much solemnity, during which lamps were placed before the houses, and kept burning throughout the night; the Jews also celebrated their *festum encæniorum* in like manner. According to Æschylus, it would appear that the Greeks had their nights of public rejoicing; and there can be no doubt that the Romans were continually in the habit of lighting up the streets with lamps and torches whenever an event of public importance commanded their attention. In some instances these displays were wholly unpremeditated, as when an orator distinguished himself in the senate, or a soldier in the camp. Cicero was thus honoured when he defeated the conspiracy of Catiline; and many a Roman general has been encouraged in his march by a like display of public enthusiasm."

It is remarkable what a lapse of inventive genius, with public and private enterprise, occurred over so many centuries throughout Europe, after the fall of the Roman empire, in respect to all matters pertaining to utility and ornament. In fact, if we look back but two or three centuries, we shall find that little progress had been made up to that time, from the period to which we alluded, in regard to almost every branch of art and manufacture requiring artistic skill or scientific knowledge. Indeed, until the beginning of the eighteenth century, not a large city in Europe was publicly lit in the streets, with the exception of London and Paris; and these were illuminated in a manner that was all but useless for passengers. We can only picture to ourselves the condition of the streets, two hundred years ago, of any large European city, by imagining the deprivation of gas for one night only in London. So much is the system of artificial illumination interwoven with all public and private engagements, that such an occurrence would now be considered a serious calamity. But, in our day, the inconvenience and danger would be infinitely less than it was in the time of Elizabeth or the Charleses; for our system of roadway, paving, and police would considerably mitigate the evil; whilst, in those days, all these were absent. Such a condition as utter darkness at night can only be contemplated with astonishment as having existed at even a still more recent date, and, to some extent, within the memory of many living; for it is only since the commencement of the present century that gas became at all in regular use: and, previous to that, only the old miserable oil-lights were occasionally met with, even in the best streets of the metropolis. Indeed, at the present day, an occasional relic of an overhanging iron projection, or arch, may be seen at the doors of some of the older mansions in the metropolis; and also inverted cones, in which torches were placed to light persons going in or out of their houses.

In respect to artificial illumination in all its most valued forms, it was reserved for chemistry to effect a complete, sudden, and decisive revolution.

About 1792, Murdoch first laid the foundation of gas-lighting, not as a system, but as a possibility; and the subsequent researches of Chévreul into the nature of fats and fatty acids, equally laid the foundation of all the improvements that have since resulted in the purification of burning oils, and of the manufacture of stearine, margarine, composite, and other such candles, that now, almost universally, with the paraffin candle, have supplanted the old tallow dips and moulds. As before hinted, up to these discoveries but little real progress had been made in the art of lighting, internally or externally, since the days when Pompeii was destroyed.

In these introductory remarks, we must not anticipate the more detailed examination and exposition of Chévreul's discoveries except by a very brief explanation, given in order that our readers may be enabled to perceive the bearing of the matter in respect to the history of artificial illumination.

Taking common tallow as typical of all other fatty bodies that can be similarly treated, it may be first observed, that it is not a single or simple body, but really consists of a mixture of at least three compounds—oleine, stearine, and margarine—glycerine being omitted as not pertinent to our present purpose. If common tallow be melted, and then cooled gently, being constantly kept in motion, and when in a pasty condition it is pressed in bags, the oleine and stearine may be separated, the former exuding as an oil from the tallow, whilst the stearine remains as a white solid, very much harder than the tallow from which it is obtained.

But it is not simply in the harder nature of stearine over tallow that its advantages consist. It will be found, on trying the experiment, that whilst the tallow melts at a temperature not exceeding about 100°, stearine requires one of about 145°. It is in this change of the melting-point that, practically, the value of removing the oleine exists; and as we shall see, in our subsequent pages, it is a point of great importance in the manufacture of modern candles, or rather those that have of late years come into so much use.

But the method of a mechanical nature, just described, produces incomplete and not uniform results; and subsequent processes were devised, resulting from Chévreul's discovery that oleine, stearine, &c., are really acids, as much as any body that can be called by that name, and just as capable of forming salts. In the ordinary method of soap-making, indeed, this fact is taken advantage of. The alkali is heated with melted fatty matter and water, and so unites with the stearic and other acids, forming veritable salts.

If to such a salt, or soap melted in hot water, dilute sulphuric acid be added, the alkali soda, till then in union with the fatty acids, is detached from them, owing to its superior affinity for sulphuric acid. Chemical decomposition, indeed, takes place, and the stearic, with the other acids, are set free. Omitting many minutiæ of the processes employed, it may be added that the stearine is then separated by washing, and subsequent hydraulic pressure, when, after further purification, it turns out a solid, having much the appearance of the best ivory.

Now, although this process is not adopted commercially, because of its expense, still it fully illustrates the results that Chévreul obtained, and that have formed the basis of all other cheaper and simpler methods. And, more than this, it has led to the use of substances that, previous to his discoveries, were valueless for candle-making. We refer to palm oil, cocoa-nut oil, and the long list of vegetable fats, butters, or oils, which are now so much employed for candle and soap-making.

Parenthetically, it may be observed, that Chévreul's discovery has not only had these great commercial effects, and conferred such valuable domestic conveniences that arise from the manufacture of a better and purer article for house illumination, it has also extended a trade on the coast of Africa, and inland, that has done more to destroy that iniquitous traffic in human flesh and blood—the slave-trade—than all the laws, penalties, and cruising vessels had hitherto effected. That obtuse and brutal animal, too well known as the African chief, has found that it is more to his advantage to retain his people, or his prisoners, and get money or goods out of their labour, instead of selling their bodies. With this fact has disappeared, to a very large extent, the dreadful slaughter often entered on to procure prisoners for sale, and the horrors of the "middle passage," or the voyage from Africa to the West Indies, which formerly paid the wretches engaged in the trade, if they could land only a fraction of their living cargo, leaving, perhaps, a dead body behind them at every two or three miles of their voyage, on an average.

This historical account of the sources of artificial light, in the form of candles, may be concluded with a notice of paraffin, on which, of course, we shall subsequently have to considerably enlarge. Paraffin, till about a quarter of a century ago, was only a chemical curiosity; and it is only from the year 1855-'56, that its valuable properties have become recognised by the public in respect to its use as a burning and lubricating oil, and of the solid matter now so largely used in making "gas candles."

It is a direct product of the distillation of certain kinds of coal, at a temperature barely that of a red heat. Mr. Young, at Bathgate, near Edinburgh, was the first to make this substance of any commercial value. Originally it was entirely obtained by the distillation of Boghead coal, abundant near the town just mentioned. But subsequently this valuable mineral has been found to extend over a vast range of country; and the production of paraffin, since the expiry of Mr. Young's patent, has become of great importance as a manufacture.

On distillation, the coal yields a variety of volatile matters, which are separated by distillation and the action of alkalies and acids. The oil is first obtained, and has now become, with the much more impure article of American origin, petroleum, enormously used as a light-giving agent in lamps, and for lubricating purposes. The solid paraffin is the last product obtained by pressure, &c.; and is a most excellent and beautiful material for candle-making, being very white, and of a pearly lustre.

The history of gas-lighting is of much interest, and can be here but briefly discussed, but it will hereafter be dealt with in detail. Within a period of half a century gas has become

universally employed for house and street illumination, and it is more than probable that now the total amount of capital employed throughout the world exceeds £100,000,000. In London, alone, about £12,000,000 is thus invested.

One of the earliest accounts of the recognition of the illuminating power of coal-gas, is that contained in a paper communicated to the Royal Society, by Thomas Shirley, in 1667. It is as follows :—

"About the latter end of February, 1659, returning from a journey to my house in Wigan, I was entertained with the relation of an odd spring, situated in one Mr. Hawkley's grounds (if I mistake not), about a mile from the town, on that road which leads to Warrington and Chester.

"The people of the town did affirm that the water of this spring did burn like oyle, into which error they suffered themselves to fall for want of due examination of the following particulars.

"For when I came to the said spring (being five or six in company), and applied a lighted candle to the surface of the water, 'tis true there was suddenly a large flame produced, which burnt vigorously; at the sight of which they began to laugh at me for denying what they had positively asserted; but I, who did not think myself confuted with laughter grounded upon inadvertency, began to examine what I saw; and observing that this spring had its eruption at the foot of a tree growing on the top of a neighbouring bank, the water of which filled a ditch that was there, and covering the burning-place lately mentioned, I then applied a lighted candle to divers parts of the water contained in the said ditch, and found, as I expected. that upon a touch of the candle and the water, the flame became extinct.

"Again, having taken up a dishful of the water at the flaming-place, and held the lighted candle to it, it went out. Yet I observed that the water at the flaming-place did boil and heave like water in a pot on the fire, though my hand put into it perceived it not so much as warm.

"This boiling I conceived to proceed from the eruption of some bituminous or sulphureous fumes, considering this place was not thirty or forty yards distant from the mouth of the coal-pit there. And, indeed, Wigan, Ashton, and the whole country, for many miles' compass, is underlaid with coal. Then, applying my hand to the surface of the burning-place of the water, I found a strong breath, as it were a wind, to bear against my hand.

"Then I caused a dam to be made, and thereby hindering the recourse of fresh water to the burning-place, I caused that which was already there to be drawn away; and then applying the burning candle to the surface of the dry earth, at the same point where the water burned before, the fumes took fire, and burned very bright and vigorous. The cone of the flame ascended a foot and a-half from the superfices of the earth. The basis of it was the compass of a man's hat about the brim I then caused a bucket of water to be poured on the fire, by which it was presently quenched, as well as my companions' laughter was stopped, who began to think the water did not burn.

"I did not perceive the flame to be discoloured like that of sulphureous bodies, nor to have any manifest scent with it. The fumes, when they broke out of the earth, and pressed against my hand, were not, to my best remembrance, hot."

There is much of sturdy sound sense and Baconian method of reasoning and experimenting expressed in the preceding quotation, evincing that Mr. Shirley was possessed of a considerable portion of those qualities that render a man to be relied on in connection with scientific matters. It is a pity that he had not thought of collecting some of the gas, and of studying more leisurely its properties. Possibly, the use of gas, as an illuminating agent, might have been much hastened had he done so.

The gas so emitted was the same that causes the fire-damp of mines, and the explosion of which, with air, is frequently the cause of many fatal accidents in coal mines. Numerous results, of a similar kind to those described by Mr. Shirley, were subsequently observed by other persons; and next in value and order may be mentioned a paper, communicated by Dr. Clayton to the *Transactions of the Royal Society*, in 1739. In this case the worthy Doctor exceeded the steps of Shirley. He collected some of the gas, and proceeded to make experiments as to what had caused it. The account of these experiments is so exceedingly quaint, and yet perfectly predicative of the subsequent use to which coal-gas was applied, that we shall not hesitate to give a short abstract of such portions of the paper as are most of interest.

. . . . "Having got some coal from one of the nearest pits, he distilled it in a retort in an open fire. At first there came over only phlegm (tarry matter of our day); afterwards a black oil, and then also a spirit arose, which he could no ways condense; but it forced the tubing, or broke the glasses. On one occasion, when it had forced the tube, coming close to it to try to repair it, he observed that the spirit which issued caught fire at the flame of a candle, and continued burning with violence as it issued out in a stream, which he blew out and lighted again, alternately, several times. He then tried to save some of this spirit; taking a turbinated receiver, and putting a candle to the pipe of the receiver while the spirit rose, he observed that it caught flame, and continued burning at the end of the pipe, though you could not discern what fed the flame: he then blew it out, and lighted it again several times; after which he fitted a bladder, flatted and void of air, to the pipe of the receiver. The oil and phelgm descended into the receiver; but the spirit still ascended, and blew up (filled) the bladder. He then filled a good many bladders with it, and might have filled an inconceivable number more, for the spirit continued to rise for several hours, and filled the bladders almost as fast as a man could have blown them with his mouth; and yet the quantity of coals he distilled was inconsiderable.

"He kept this spirit in the bladders a considerable time, and endeavoured several ways to condense it; but in vain. And when he wished to amuse his friends, he would take one of these bladders, and pricking a hole with a pin, and compressing gently the bladder near the flame of a candle till it took fire, it would then continue flaming till all the spirit was compressed out of the bladder.

"But then he found that this spirit must be kept in good thick bladders, as those of an ox or the like: for if he filled calves' bladders with it, it would lose its inflammability in twenty-four hours, though the bladder became not at all relaxed."

Dr. Clayton, in the above extract, shows that, for want of a little further trial of the qualities of this "spirit," or more properly gas, he missed making three great discoveries in connection with science: first, the adaptability of coal-gas to illuminating purposes; secondly, the nature of the phlegm and oil, whence we now obtain the splendid and valuable aniline colours, &c.; and, lastly, the law of the transfusion of gaseous bodies through septa, which is now recognised as a most valuable property, under the phenomena of dialysis.

Subsequently these curious results were witnessed, and the experiments repeated, by others. The Earl of Dundonald, towards the close of the last century, actually took a patent out for distilling coals to obtain coke and tar. Instead of, however, utilising the gas, it was allowed to escape into the open air as a *waste* product; affording another of the many remarkable instances, common in the annals of scientific history, of the narrow escapes many persons have had of attaining riches and reputation, because they had not sufficient knowledge to avail themselves of their discoveries.

It was not until the year 1792, that any definite results were arrived at in respect to the utilisation of coal-gas as an illuminating agent. In that year, Mr. Murdoch, of Redruth, in Cornwall, entered on a series of experiments, with the object of not only producing, but of purifying coal-gas. He also examined various kinds of coal, for the purpose of seeing which gave the greatest quantity of gas, weight for weight. His first plan of purifying was by the usual method of washing gases—namely, by passing the coal-gas through water; in which attempt, it need only be stated, he failed. Of course, at that time, chemistry itself was an infantile science, and the means of analysis, gaseous, solid, or liquid, were far from being trustworthy.

In 1798, Mr. Murdoch moved from Redruth, and proceeded to Boulton and Watt's factory at Soho, near Birmingham—the celebrated engineering firm wherein James Watt gained his great reputation for improvements of the steam-engine. Here Murdoch resumed his experiments on the large scale, and succeeded in lighting up the establishment with coal-gas. He also engaged in fresh attempts to purify the gas; in which, however, he only partially suceeded, owing, as before stated, to the exceedingly incomplete condition of chemical knowledge at that period. At the illumination to celebrate the general peace, in 1802, the whole front of the Soho works was lit up with coal-gas.

The success of Murdoch soon became noised abroad, and led to numerous experimental attempts to establish the use of coal-gas as an illuminating agent. The factory of Messrs. Phillips and Lee, of Manchester, was the first lit up with gas.

In an extremely modest form Mr. Murdoch described his earliest attempt at rendering gas an illuminating agent. Fortunately for him, he fell into good hands, not only in respect to a question of capital, but also that of enterprise, on the part of those with whom he first engaged himself. This circumstance may be considered as of primary importance in the history of gas illumination; and as such, could not, of course, be passed by.

But whatever credit is due to Mr. Murdoch, it must not be supposed that he alone was in the field. In France, M. Le Bon, so early as 1802, had utilised the gas produced by the dry distillation of wood and coal for illuminating purposes; entitling the lamp employed in the combustion of the gas, the *Thermo-lamp*. From the success of this inventor, Mr. Winsor, an Englishman, was induced to make some experiments in gas illumination. He first visited Paris to try to extract the secret from Le Bon; but failing in this, he started on his own account; and in the autumn of 1802, exhibited before the notabilia of Brunswick, the results of his first success, apparently ignorant of that which had already been arrived at by Murdoch in this country. In 1803, however, Winsor ventured on a public exhibition at the Lyceum Theatre, in London; and, in 1804, took out a patent for his invention. In 1807, he had succeeded in lighting up a portion of Pall Mall with gas—a novelty which excited great interest on the part of Londoners. We believe that Mr. Winsor was the first to employ lime, and subsequently "milk of lime"—that is, lime slaked with water to a consistency resembling milk—for the purpose of purifying gas—a plan still largely adopted, despite numerous other methods to which we shall afterwards allude, as used at the present day.

We thus notice that, by divers means, gas was, at that date, rapidly becoming of importance for the purpose of artificial illumination, despite opposition, arising especially from scientific circles, where, at least, we might have supposed common sense, at the lowest estimate, would have had some chance of asserting its right. We have already mentioned that Sir Humphry Davy early set his face against gas. It is amusing, at this day, to remember what he cynically said to Mr. Clegg—that he supposed the latter would require, some day, the dome of St. Paul's for a gas-holder—a prophecy, although ironically uttered, far more than verified at the present day in respect to fact, for several gas-holders in this country, exceed in diameter, and cubic capacity, the dome of that cathedral—in respect to diameter, by at least 100 feet! To show still further the animus that even scientific circles had against the gas, we may add that, in 1813, Sir J. Banks headed a deputation which visited the Chartered gas-works; and after inspecting the proposed plans, recommended that the gas-holders—or, as they are now commonly called, gasometers—should not exceed a cubic content of 6,000 feet, an amount that would easily be run through by some large London establishments in an evening in our time.

The first public act passed to form a gas company, was obtained by Winsor. Barlow says—"In 1809, Mr. Winsor and his friends applied to parliament for an act of incorporation, with liberty to raise a capital of £200,000 (which we may here state, is considerably less than *half* of the total amount of annual profit divided amongst the London gas companies at the present day, exclusive of interest on borrowed money); the application, however, was not successful, partly in consequence of Mr. Murdoch's opposition, who brought forward, apparently to the satisfaction of the parliamentary committee, the proofs of priority of discovery. The application, however, was renewed in the next year. Though it encountered some opposition, and incurred considerable expense, yet the parties succeeded in obtaining an act to authorise his majesty to grant them a charter within three years from the time of passing the act. But the bill as originally introduced was materially altered, and certain conditions were imposed, which limited their powers to London, Westminster, Southwark, and the suburbs adjacent. Besides, it was stipulated that, if required, they should contract with the parishes of London, Westminster, and Southwark, to furnish a stronger and better light, and at a cheaper and lower price, all expenses included, than such parishes could be supplied with oil, if lighted in the usual manner. Their capital was limited to £200,000, which was to be raised in shares of £50 each; they were not authorised to exercise any of the powers granted by the act till such time as £100,000 were subscribed; and the act also obliged them to raise the full amount of £200,000 within three years from the time the charter should be granted." Various arrangements were made for controlling the management of the company; and thus the first step was taken for establishing associations for the purpose of manufacturing and supplying gas on the large scale for public and private use.

The name of Mr. Clegg has been already mentioned as associated with the early history of

gas; and he appears to have been amongst the first to have taken the subject into active consideration, as, so early as 1804, he arrived at some practical results in erecting gas apparatus at a cotton-mill at Halifax, Yorkshire, and engaged in similar operations in subsequent years. In 1813, he became gas engineer to the Chartered Gas Company of London; and his name has ever since been more or less connected with gas questions.

One explosion which took place at the Chartered works at Westminster led to the appointment of a select committee of the House of Commons in 1823—the year, at least, in which the report was made public, although it was resolved on in 1814. A few brief extracts, or rather *résumés*, will give some idea of the status of gas companies, and other allied matters, at the commencement of the gas-lighting system.

The early part of this report states, that the danger likely to arise from gasometers and gas-works is not so great as has been supposed; and, consequently, that the necessity of interference "does not press at the present period of the session. . . . It appears that great improvements have taken place in the apparatus, machinery, and management of gas-works since 1814, the date of the report from the committee of the Royal Society, which have very much lessened the danger of such works. . . . The evidence sufficiently supports the opinion that risk of accident or danger is but small, if the ordinary care and attention necessary in every large establishment be paid by the officers and workmen employed on the premises. . . . The danger attendant on the use of gas in the streets and passages, appears also to be small. . . . It appears that in some of the gas-works, safety-lamps, on Sir Humphry Davy's plan, are used on the premises, to guard against accidents that might occur by the application of flame to any explosive mixture that might have been formed by leakage from the gasometers or pipes; and as the committee considered that precaution very necessary, they trust the directors of every establishment will immediately adopt them, both for their own and the public security." This latter precaution, so urgently pressed on the "directors," would not run much chance of being heeded in our day; in fact, it is amusingly illustrative of the excess of caution that was entertained in the early days of gas-lighting. Generally, the report was much in favour of establishing gas companies, and of allowing them all facilities for their manufacture.

The examination of Sir Humphry Davy, and his replies (generally of a really scientific character, but, occasionally, in the absence of fact, speculative), certainly does not greatly elevate either the scientific or practical knowledge of that day in our estimation. The earliest inquiries put to him were in reference to the safe point in respect to the size of gasometers; and he certainly took every precaution not to commit himself in his answers. Amongst other replies to questions put to him, was one to the effect—That, with proper precaution, would a gasometer, of a capacity of 20,000 cubic feet, be pretty well removed from danger? To which he replied—"I think so; the danger must be increased according to the size of the object bursting, and the explosion from it." It would surprise Sir Humphry to see, at the present day, one gasometer in constant use, the capacity of which exceeds 3,000,000 cubic feet of gas. We have already noticed his cynical remark to Mr. Clegg, in respect to the use of the dome of St. Paul's Cathedral as a gas-holder; which, as previously stated, is greatly less in diameter than many gas-holders now in ordinary use.

Dr. Wollaston was similarly examined before the same committee; and, without reproducing his evidence in this work, we can but express the opinion that, for sound practical sense, his replies to the inquiries put to him were highly characteristic. It will amuse many of, but especially our practical readers, to find that such questions as the following were addressed to him; which we give, with his replies:—

"Do you think that there is more danger and more difficulty in the management of a gas-light establishment than there is in the management of gunpowder?"—"Most certainly not; most certainly much less precaution is necessary against accident."

"In your opinion, supposing the establishments to be conducted by very skilful and attentive persons, is the danger of explosion, under such circumstance, small or great?"—"I presume it to be very small. It requires such a concurrence of circumstances to have an explosion take place; the admixture of a due proportion of common air with the gas, and then fire to be put to it at the proper time. There are various cases in which two circumstances are requisite, and various others in which three are requisite. I do not recollect having noted more than three; but where three conditions are requisite, the probability is so remote that I should not trouble myself to estimate the danger."

One leading idea at the time to which we refer was, that the explosive effects of a mixture of gas and common air should be judged of by those of ignited gunpowder; and, consequently, a report was made by a committee of the Royal Society to aid the commissioners, entitled *Estimate of the Force of Explosion of Coal-Gas, laid before the Committee of the Royal Society in the year* 1814, *by one of its Members*. In this production, which was believed to have been from the pen of Dr. Young, there is evidence that mathematics, and every other branch of science, may be most effectively, for the time, perverted to any purpose. Elaborate calculations were entered into to show the extent, diffusion, and amount of explosive effects that gas and air mixed together might produce, based on no facts whatever, but merely on a congeries of suppositions, which, like a house built of paper or card, could be demolished with a breath. In fact, the early days of gas-engineering, as of that of railways, were characterised by parliamentary, Royal Society, and scientific stupidity.

One evidence of the ignorance of those days in respect to the commixture of gases by diffusion, and which may, by a small leak in a gasometer, become dangerous, is found in the reply to the following question put to Professor Millington, of the Royal Institution:—Is there not so strong a chemical attraction between gas and atmospheric air that the lighter air will even descend to mix with the heavier?"—"That must be a slow process." In later years, Faraday and Graham would have given a very opposite and more decided answer; in fact, now the rapid diffusion of all fluids, gaseous or liquid, has become a point of great recognised importance in physical science, as already mentioned.

Despite the opposition and ignorance of science, falsely so called, gas made headway; and, according to a report of Sir William Congreve, one of the members of the parliamentary committee, before whom the evidence already adduced was given, several gas-works, some of which are still existing, were established in the metropolis. He reports that, in 1823, there were 300 retorts at the Peter Street station, of which the greatest number at work was 221, and the least eighty-seven. Fifteen gasometers, averaging about 20,626 cubic feet, stored, in all, about 310,000 cubic feet of gas. The mains of this station extended to fifty-seven miles linear length. The annual consumption of coal was about 9,300 chaldrons, affording 111,384,000 cubic feet of gas. From this there were lighted 10,660 private, 2,248 street, and 3,894 theatre lamps. The Brick Lane works had 371 retorts, of which 217 were the maximum, and sixty the minimum at work. The gasometers were twelve in number, averaging each a capacity of 18,427 cubic feet, and, in all, storing 221,131 cubic feet; their working average being 197,124 feet. The annual consumption of coal was 8,060 chaldrons, affording 96,720,000 cubic feet. The number of lamps supplied was 1,978 public, and 7,366 private, with forty miles of mains. At Curtain Road, the total of retorts was 240; maximum in work, eighty, and the lowest twenty-one. That establishment had six gasometers, with an average capacity each of 15,077 cubic feet; the contents of the whole being 90,467. The consumption of coal annually was 3,336 chaldrons, and quantity of gas supplied 40,049,000 cubic feet. Besides these, which supplied annually about 250,000,000 cubic feet of gas, there was the City of London, in Dorset Street, affording 106,080,000 feet; the South London Gas-light and Coke Company, and the Imperial Gas-light and Coke Company—now merged with the Gas-light and Coke Company. The total supply of gas estimated, according to the report from which the preceding facts have been drawn, in 1822-'23, amounted to 397,000,000 cubic feet; lighting 61,203 private, and 7,268 public lamps, independently of the supply afforded by smaller companies, from which no return had been obtained. The existing supply in London alone, renders the statistics above given amusingly small, one company affording many thousands of millions of cubic feet to its customers in London annually, at the present day.

We have so far traced the history of the practice of artificial illumination from the earliest days of our race to the present expansion of the gas system. There are two other methods to which we must now briefly allude; one the Lime or Drummond Light, and the other the Electric Light, which has recently been extensively used for illuminating public buildings, streets, docks, railway stations, and other places.

The Lime, Oxy-hydrogen, or Drummond Light, is produced by the combustion of the gases oxygen and hydrogen; the flame thus, although not luminous, producing a most intense white light when allowed to impinge on lime or magnesia; the former, however, being mostly used, as it can be easily cut or turned into cylinders, which is the most suitable form for its employment.

According to the original method of obtaining this light, oxygen, afforded by heating the black oxide of manganese, and hydrogen by the decomposition of water, were mixed together in a bladder. The mixed gases were then passed through a tube filled with circles of wire gauze tightly packed, or through a tube, also tightly packed with thin rods or wires; the object of both plans being to prevent the retrogression of the flame through the jet to the bladder, or other receptacle of the gases—a result which would be accompanied with a violent explosion. Eventually, however, it was found far safer to keep the gases in two separate holders, and only to allow them to mix as they issue from the jet. A pipe of small bore, in the best form of the jet, is inserted in one of a little larger bore. Between these pipes the hydrogen finds its way from the holder to the jet, where it is ignited. The small internal tube being attached to a holder filled with oxygen, this gas is then turned on. The yellowish-red flame of the hydrogen is thus lost, and a blue one, of intense heating power, is afforded, the length, &c., of which is kept uniform by regulating the supply of either or both gases by means of stopcocks.

A constant jet of flame may be thus kept up so long as the supply of the two gases is maintained. It is cast on to a cylinder of hard lime, about an inch and a-half high, and three-quarters of an inch in diameter, and instantly, on touching it, a dazzling bright light is afforded. The cylinder is usually kept vertical; and as portions of the lime are volatilised by the intense heat, the cylinder is kept rotating by means of clock-work, so that fresh surfaces shall be continually exposed to the action of the flame.

The amount of light thus produced is exceedingly great, and its penetrative power is equally so. By means of a parabolic reflector, this light has been directed to a station sixty or seventy miles from its source, and was distinctly visible.

Owing to its brilliancy and penetrative power, it was first proposed and used by Lieutenant Drummond as a means of night-signals in the trigonometrical survey of Ireland; his early experiments being reported in the *Transactions of the Royal Society*, in 1830. At that time the inventor had sanguine hopes of converting it into a means of lighthouse illumination; and extensive experiments were undertaken to adapt it for that purpose. Like however, many other excellent scientific inventions, admirable in the laboratory and lecture-room, it was found inconvenient and practically impossible; and for many years its uses were mostly confined to the illumination of dissolving views at some public institutions, varied with an occasional outburst of some possible application, that, however, up to the present time, has never been made. The last attempt that we witnessed of this kind was that of lighting up old Westminister Bridge. The effect was most beautiful: but the experiment terminated, after a few days, in an accident that, we were informed, proved fatal. Indeed, to deal with such gases as oxygen and hydrogen safely, requires long practice, and some scientific knowledge; and even with these requirements we have witnessed accidents, that, but for collateral precautions, would have resulted in very serious results, where but small holders or bags of the gases, that had accidentally mixed, exploded through retrogression of the flame, or other cause.

Of course, in attempting to apply the lime-light to lighthouse illumination, many objections arise. Usually such places are at some distance from any town or port whence the materials can be obtained or shipped for use. Near gas-works, coal-gas may be substituted for pure hydrogen, as it is just as effective, only requiring more oxygen, but still doing away with the necessity of decomposing water. Yet the manufacture of oxygen, although apparently simple, requires many precautions; is attended by considerable expense; requires the erection of gas-holders, &c. To obviate these objections, it was at one time proposed to substitute the decomposing action of the voltaic battery (to be presently described) on water, and thus cause the simultaneous evolution of the gases in exactly such proportions as are required for the purposes of the lime-light. When this was first proposed, we fitted up an apparatus, of the best construction, for the purpose; but found, that, whilst very interesting as a lecture-room experiment, or as a matter of surprise in the illumination of a room for an evening party, the method is attended with far too much trouble, expense, and difficulty, to make the proposition of the least practical value. Another objection is, that no voltaic battery will keep long in steady action. The most powerful, and best charged—that is, any form of the nitric acid battery—cannot be depended on for more than an hour; after which they rapidly fall off in power, until they are far below what would be required to keep a decomposition of water sufficient to supply the mixed gases for an ordinary lime-light, and for lighthouse purposes.

We next turn to a short description of the history of the electric light, that was long ago

proposed as an illuminating agent for light-house and other purposes requiring intense penetrating power, but has only recently been brought into comparative perfection. This light, whilst primarily derivable from current electricity, is, so far as the production of the latter is concerned, dependent both on chemical and magnetic induction, but now especially on the latter.

The voltaic battery is an arrangement by means of which the latent electricity of water is set free. It essentially consists (at least, so far as any usual form of cell or battery is concerned) of two metals, and one or more liquids. In the old forms, a plate of copper was placed facing one of zinc, in a vessel containing water, acidulated by either sulphuric or nitric acid—sometimes both—the zinc of one vessel being connected with the copper of the next; and so on through a series of any number. The extreme zinc and copper of the series had each a wire attached; and at the other extremity of these wires the electrical effects are manifested. In such an arrangement, as soon as the two terminal wires are caused to touch each other, a current of electricity is generated, that passes through the whole series. If these wires be thus brought in contact and then separated, a bright spark passes; and if the battery be sufficiently powerful, this spark is continuous, becoming a bright arc of light, the length and brilliancy of which depend on the energy of the battery. Its colour is influenced by the nature of the wires, all the metals giving coloured flames, whilst that of charcoal is nearly white.

But such a form of battery is far too inconstant in its action to be of the least use as a light-producing agent. Even within a minute or two after it is excited, and the current is produced, its power degenerates, unless the battery be of great extent—as that Sir Humphry Davy employed, containing about 2,000 pairs of plates, which was constructed on the imperfect plan just described.

The first step for bringing the voltaic battery into possible use as a light agent, was the invention of the constant battery by Professor Daniell. In this zinc and copper are used, as above; but in place of acid and water alone, two solutions, separated by a porous diaphragm, are used—near the zinc, one of dilute sulphuric acid; that next the copper is composed of a saturated solution of sulphate of copper, to which an eighth portion of sulphuric acid has been added. Crystals of sulphate of copper are suspended in the solution to keep up its strength.

Such a battery we have kept in equal action for three or four hours together; after which its powers lessens, owing to the sulphuric acid becoming saturated with zinc, when the production of electricity gradually falls off.

Grove's battery, or its modification, is really the only one that can be practically employed; for, whilst having considerable constancy, it has far greater power than either of the preceding. In it platina—next which is strong nitric acid, separated by a porous pot from water, to which a sixth part of sulphuric acid is added—and zinc are the metals used. Owing to the energetic action of the battery, a force may be generated by one occupying a space two feet square and six inches high, that will afford a light equal to 2,000 sperm candles: in other words, speaking in comparison with gas, equivalent to 100 jets of twenty-candle gas, all burning at once; with a light, however, greatly superior in whiteness.

When the terminal wires of such a battery are tipped with a piece each of charcoal, or hard gas carbon, and these pieces be touched together and withdrawn, a most brilliant arc of flame is produced, resembling that represented in the annexed cut. An arc of the size here illustrated, although so small, would afford a light quite equal to that just described—that is, of 2,000 sperm candles burning at once.

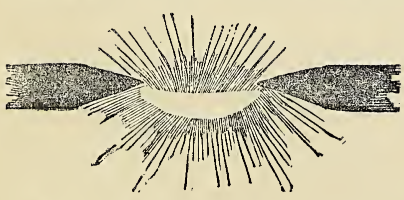


Fig. 51.—Arc of the Electric Light.

We have omitted to enter into any description of other forms of voltaic batteries, such as the carbon (or Bunsen's) and the iron (or Callan's), in both of which nitric acid is employed, their construction being precisely similar, together with their principles of action, to Grove's, than which, from the substitution of carbon from gas retorts, or cast-iron, they are cheaper in construction.

As might be expected, numerous patents were taken out by inventors for the purpose of applying the Electric Light for artificial illumination. One of the earliest was that of Mr. Staite,

whose experiments we witnessed in front of the National Gallery in Trafalgar Square, London, in or about 1846. But owing to the defects of the voltaic battery to which we have already alluded—viz., its inconstancy, and the necessity of the renewal of its arrangements every few hours, all attempts of the kind failed.

Eventually, magneto-electro machines were substituted for the voltaic battery, and hence a great advance was made, because a constant production of electric force could be maintained simply by employing a steam-engine to drive the magneto-electric machine. The electricity derived by such machines may be briefly described, for the present, as produced in the following manner. If a horse-shoe or other magnet be made to revolve before a piece of soft iron, covered with insulated copper wire wound over it, in the shape of a coil, each time the pole of the magnet passes the end of the iron, a current of electricity is generated in the wire, or what is preferable, the iron core covered with the wire is made to revolve in a position so that its end may pass in front of the poles of the magnet. The oftener such passages are made, the greater are the number of the currents of electricity produced, and hence we have here, thanks to the discovery of Faraday, an unlimited power of producing electricity for any purpose, simply by mechanical, instead of chemical agency, as is the case in the voltaic battery. The magneto-machine, therefore, does away with all the chief objections that existed against the chemical mode of producing Electricity. When we describe the various modern machines of Gramme, Siemens, and others, we shall enter fully into the details of this subject.

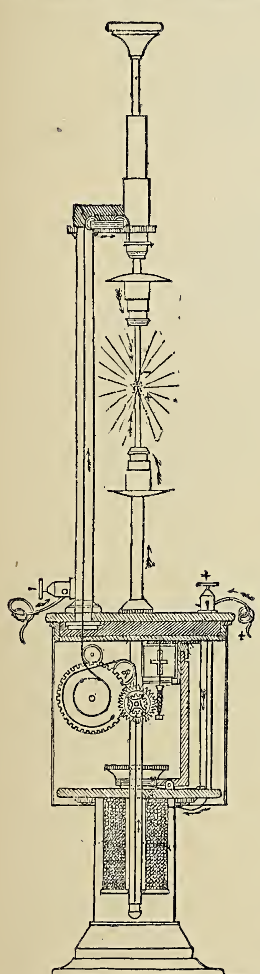


Fig. 52.—Duboscq's Electric Lamp.

But another difficulty had to be overcome. The charcoal points in the old form of the electric lamps constantly burnt away. For our readers to understand this, it must be observed, that although *no combustion* really goes on whilst the electric light is in operation —for it will show equally well in hydrogen, or under water—one point or pole gradually increases in size, whilst the other decreases, and works into hollows. The light, in fact, depends on the rapid transference of minute particles of carbon from one pole, or electrode, to the other; and thus, whilst one is constantly increasing in size, the other is as fully lessened, independent of a slight loss by combustion, which, although not a condition of the electrical light, as above stated, necessarily in most cases attends its production.

The essential question, therefore, has been to invent such an arrangement as shall keep these carbon points at, as nearly as possible, equal distances from each other, but without touching; and thus to maintain the constancy of the light: and the ingenuity of inventors has been severely taxed for that purpose.

The inventions so produced have been generally termed electric lamps. In many, the charcoal points were fixed vertically, and, by means of chain and clock, actuated at first by a key, they can be brought into contact. If this be done whilst the two poles are connected with the battery, a self-acting apparatus is called into work. A piece of iron bent into a horse-shoe form, and surrounded by insulated or covered copper wire, is then magnetised, a portion, or the whole, of the current being sent through the wire, and thus converting the iron into an electro-magnet. This acts on a soft iron keeper, and this again on ratchet or wheel-work connected with the wire holding the lower charcoal or carbon point. By such means the points may be kept, on an average, at pretty equal distances, attended, however, with an occasional extinction of the flame. But at the instant this occurs the upper charcoal point falls to the lower, or the latter rises to the upper one. They again come into contact, the current and light being consequently re-established at the same moment.

Such an arrangement was the basis of nearly all the electric lamps formerly in use. The first of the kind was brought out by M. Duboscq, of Paris (See Fig. 52), well known by his

numerous and ingenious inventions of philosophical instruments. We have had several of his in use; and, for a limited period, they answer well; but generally, being of too light construction for powerful batteries, we have had made some modifications of them, with like results.

The first inventor who really succeeded in maintaining an electric light for a definite period, was Mr. Holmes, whose magnetic-light machine was kept in almost constant action at the London Exhibition of 1862, in the western annexe. The brilliancy was so great as to illumine surrounding objects even during sun-light; and many of our readers will remember the great attraction which it afforded to visitors.

We were favoured by the inventor with a trial view of this apparatus, at the Trinity House depôt, Blackwall, at its first introduction, about twenty-five years ago. The night was free from haze, being what is usually called a fine spring evening. When darkness came on, the machine driven by a small steam engine, was set in motion, and an enormous current of electricity, induced by magnetism, was afforded. The light shed on the river beautifully illuminated the sails of a vessel a mile off, as she was tacking down the Thames; casting, at the same time, a deep black shadow of the spectators standing between the light and the wharf. The windows of a house four miles off were so powerfully illuminated as to be quite brilliant in their reflection back to a place near which the light was in course of production; and, altogether, these preliminary trials were of the most satisfactory character. Subsequently, one of these machines was transferred to the South Foreland light-house; and was kept in constant action for six months, without, we believe, one stoppage of any importance. The effect on the atmosphere, slightly hazy, was remarkable in forming a cone of rays of a comet-like character, stretching miles out to sea, and affording a most curious effect when viewed from some distance.

It is difficult for the purpose of illustrating the modern forms of the magneto-electric machines, to make a selection out of the numerous patents, most of which will be eventually described. Holmes, Wilde, Gramme, Wallace-Farmer, Edison, Siemens, and many others have either invented an individual machine, or improved on each other. They all, practically speaking, act on the same principle, but vary greatly in details, and generally efficiency. For the present, we shall choose for description and illustration, the Lontin machine.

In the Lontin machine, the revolving armature is in the form of a star-shaped wheel consisting of a central boss P, Fig. 53, into which are fixed ten or more radial bars of soft iron, circular in section but slightly conical in form, marked in the drawing D D D. Each of the radial spokes is wound with a coil of insulated copper wire, the ends of which are connected together in series, and to a cylindrical commutator. The armature wheel is fixed on a shaft and revolves in the magnetic field of two powerful electro-magnets A A, fixed vertically into a base-plate of iron by which they become the two limits of a "horseshoe" electro-magnet. The cores of the radial magnetic inductors as they revolve approach very close to and recede from the poles of the inducing magnets A A, being at their point of closest proximity when their axes pass the line X X. By Lenz's law, a coil approaching a north pole of a magnet has a current of electricity induced in it in one direction, and when receding from the same pole the induced current is in the opposite direction, and a

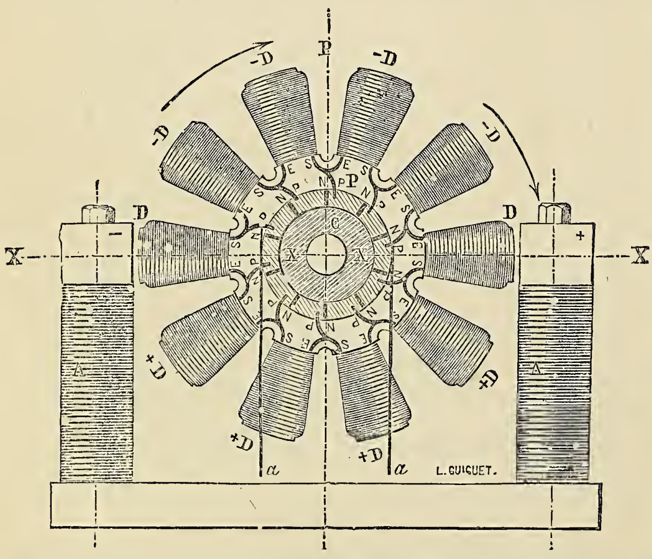


Fig. 53.—Lontin's Magneto-electric Exciting Machine, sectional view.

coil receding from a north pole has a current induced in it in the same direction as a similar coil approaching a south pole, and *vice versa*. Bearing these laws in mind, and referring to Fig. 53, it will be seen that when the machine is revolving in the direction of the arrows, all the radial bobbins, above the horizontal line X X, are receding from the left hand or south pole of the magnet A A, and approaching the right hand or north pole, while those below the line X X, are doing just the reverse, that is to say, they are receding from the north pole, and approaching the south pole; the currents induced, therefore, in all the bobbins above the line X X are similar in direction to one another, but inverse to those below the line X X. The coils in the arrangement shown in the figure are coupled together in series as in the Gramme machine, and each pair of contiguous coils is connected to a section P of the cylindrical commutator, there being as many sectors as there are bobbins, and insulated from one another by their strips of ebonite N N N. Against the surface of this commutator, collectors *a a* are pressed by means of springs, the one taking off the positive current and the other the negative, and the currents so induced are transmitted through the coils of the large vertical electro-magnets, so that the machine is on the dynamo-electric or reaction principle.

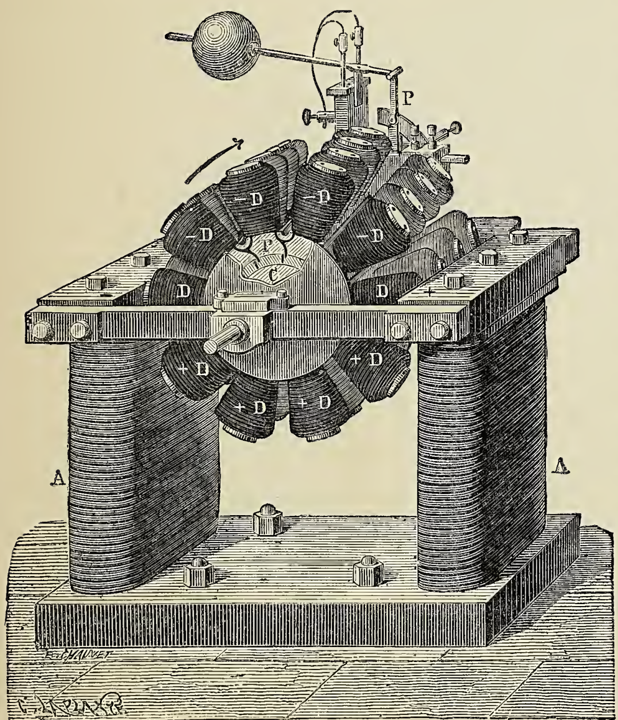


Fig. 54.—Lontin's Magneto-electric Exciting Machine, perspective view.

Fig. 54 is a perspective view of a Lontin generator with four induction wheels fixed on the same shaft, each wheel carrying ten bobbins. In this machine the ends of the iron cores of the forty radial bobbins D D D, revolve close to the horizontal pole-pieces of the two powerful electro-magnets A A, which are flat in section, and fixed in a vertical position in a solid bedplate of iron. In this machine the bobbins are attached to the central boss in such a way that the bobbins of one wheel pass the poles of the magnets a little in advance of those of the next wheel, in other words they are mounted helically on the shaft. The object of this arrangement is to obtain greater uniformity in the distribution of the mechanical resistance to the rotation of the machine—no two bobbins being at their maximum points of resistance at the same time—and to insure greater regularity in the strength of the current produced by the machine. In some of the more recent machines on this principle M. Lontin has introduced several improvements; one of these is to construct the pole-pieces of the inducing magnets A A in such a manner that their distance from the revolving induction wheels is capable of being adjusted at will, so as to increase or diminish within certain limits, to any required degree the intensity of the current produced, and by carrying the conducting wires connecting the induction wheels with the commutator through the axis of the machine (which is for that purpose made hollow for a certain portion of its length), the commutator may be placed altogether outside the machine, and the latter may be completely inclosed in a protecting casing, while the latter are perfectly free and accessible. M. Lontin makes his collecting contact pieces of an alloy of lead and tin, and they are maintained against the commutator with a constant and adjustable pressure by means of a counterbalanced lever shown at P, Fig. 54.

The machine just described is the continuous or single-current machine of M. Lontin, and it may be used with a single lamp in the place of any other single-current machine, such as the Siemen's or Gramme, both of which have a higher efficiency. The special feature, however, of M. Lontin's system of electric illumination consists in his method of dividing the current, and distributing it over a series of different lamps, producing at the same time an alternating current in each circuit, by which the carbon pencils in the electric regulators are consumed at a more uniform rate, and their extremities remain pointed, two very decided advantages in an electric lamp. In the Lontin system, as in both the distributing systems of Gramme and Siemens, two distinct machines are employed, the one being devoted exclusively to producing the current by which the inducing electro-magnets of the second machine are excited, and the other for inducing from the electro-magnets so excited a series of currents of electricity, and distributing them into a number of illuminating circuits. The feeding or exciting machine used under the Lontin system is that which we have just described, and the currents of electricity which are generated by it are led by conducting wires to the second or distributing machine which is illustrated in Figs. 55 and 56. This machine consists of a revolving cylinder of brass *a*, Fig. 55, around the circumference of which are mounted radially a number of flat electro-magnets

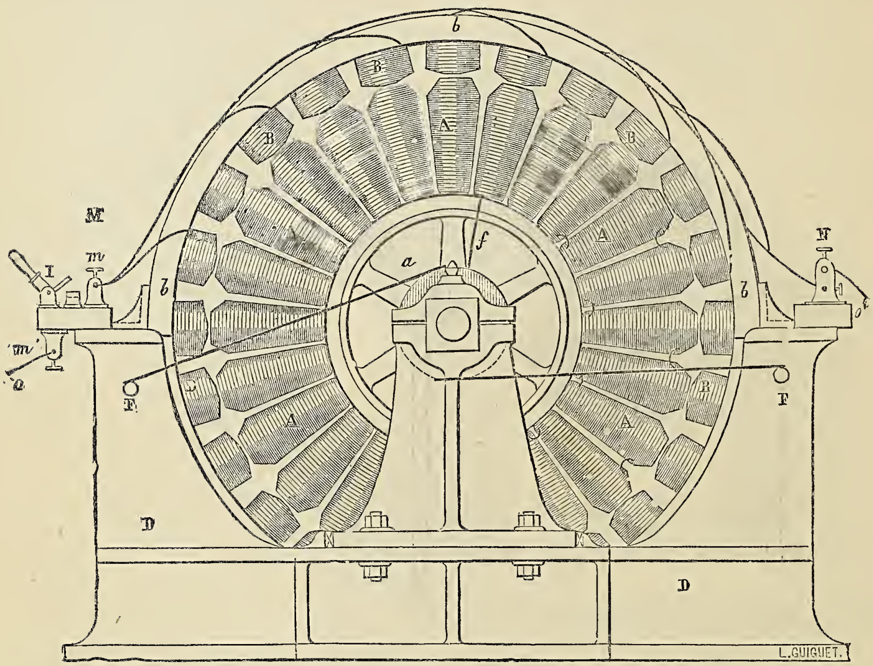


Fig. 55.—Lontin's Magneto-electric Distributing Machine, sectional view.

A A A. The coils of these magnets (shown endwise in the illustration, which represents the end elevation of a machine having twenty-four inductors) are connected in series, but in such a manner that when the current from the exciting machine is transmitted through them they become a series of powerful magnets, of which every alternate magnet has one polarity, and the polarity of the intermediate magnets is in a reverse direction—that is to say, if the revolving magnets were numbered consecutively around the circumference from 1 to 24, all the even numbers would have a north pole at their outer extremity, and all the odd numbers would have a south polarity. Enveloping this revolving series of electro-magnets and fixed to the annular frames *b b b* is a crown of flat electro-magnetic inductors B B B, having their ends presented towards the axis of the machine, and therefore towards the radial electro-magnets attached to the revolving wheel. There are as many of these induction coils as there are radial magnets, and it will be seen from the construction of the machine that when the apparatus is set in motion a series of alternating currents of electricity will be induced in each of the fixed coils as the revolving magnets, alternating in polarity, approach to and recede from it. The ends of

the fixed coils are connected by suitable conductors to the terminal screws *m* of the manipulator or commutating switching apparatus M, which is best shown in the perspective view of the machine, Fig. 56. By this portion of the apparatus the current from all or any lesser number of the outside induction coils can be diverted into a number of different circuits; the number of such external circuits depending upon the size and construction of the machine, and upon the number of the induction bobbins that are capable of producing the currents required. In the machine, as shown in Fig. 55, the bobbins are coupled up in pairs, so that twelve circuits may be fed by the twenty-four bobbins. Attached to the shelf, on which the commutator switches are fixed, are twenty-four terminal screws, twelve above it marked *m*, and twelve below it marked *m'*, and by manipulating the twelve bell-crank switches I, any number of the upper terminals may be connected to any number of the lower. Thus as any of the bobbins may be connected by wires to any of the upper terminals, and the lower terminals may be connected to any of the outside circuits, the arrangements of the connexions of the bobbins, and the coupling up of the circuits, are under perfect control, and any circuit may be completed or thrown out of the machine instantaneously by a movement of the switches. The wires *o* (Fig. 56), attached

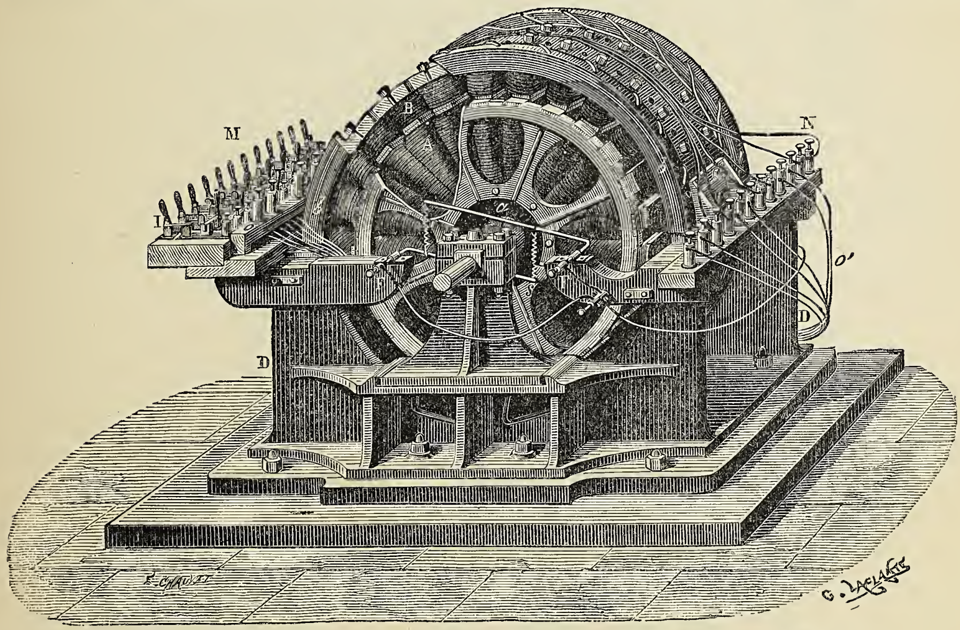


Fig. 56.—Lontin's Magneto-electric Distributing Machine, perspective view.

to the terminals *m'*, lead to the different lamp circuits, and the wires *o'*, attached to the terminals N, are the return wires from the same circuits. To the terminals F F are attached the wires leading from the exciting machine, the current of which is transmitted to the coils of the rotating electro-magnets A A by the two contact pieces *a a*, which are maintained in close contact against the contact cylinders, one of which is shown in the figure, and to which the coils of the electro-magnets are connected.

The Lontin system is that which was employed at the St. Lazare terminus in Paris of the Western Railway of France for illuminating the goods platform, waiting hall, and front of the station by the electric light in 1878, and it supplied the light to every alternate light round the balcony of the Paris Hippodrome, it being tried against the Jablochkoff system, which was in the intermediate lamps. It was also the Lontin machine that was employed for the electric lighting of the exterior of the Gaiety Theatre in London, in 1877, and is interesting for that reason as having been the first practical application of electricity to street lighting that was ever made in this country.

We have already alluded, at page lxxx *ante*, to the difficulty which was experienced in the old forms of the electric lamp of keeping the carbon points, at all times, equally distant from

each other. We might almost say that scores of inventions have been brought out to obviate this inconvenience. One of the best of these was introduced about 1874 by a Russian inventor of the name of Jablochkoff. This invention, which has since almost revolutionised the system of electric lighting, is of the following nature. Instead of placing the two carbon pencils end to end, as we have described and illustrated at page lxxx *ante*, in the case of Duboscq's lamp, he places them side by side, at about a sixth of an inch apart, and the space between them is occupied by a strip of kaolin or of plaster of Paris. Fig. 57 represents one of these candles. A A are two binding-screws which hold the wires coming from the magneto-electric machine. B B are each slips of carbon separated by the kaolin, and C is the apex at which the electric light is afforded. The electricity which arrives from the magneto-machine passes up one carbon, crosses the slice of intervening plaster at the top, and descends the other carbon on its return to the negative pole of the generator. The arc therefore has its place at the top of the "candle," in the place where the flame of an ordinary candle is. Both the carbon tops become intensely luminous, and the intervening plaster fuses and glows. It melts away as the carbons waste downwards, and the candle is therefore slowly consumed away "just like a candle." Here, however, M. Jablochkoff had a difficulty to contend with. The carbons waste at unequal rates, the positive carbon being consumed nearly twice as fast as the negative. The first attempt to remedy the defect, by having a positive carbon of twice the thickness of the negative, did not meet with practical success. M. Jablochkoff therefore devised a machine, which should produce, like the early magneto-electric machines, not a continuous current, but a series of alternate currents following one another with great rapidity. A commutator on this principle, reversing the current 6,400 times a minute, can be applied to the Gramme machine. M. Gramme has also constructed for M. Jablochkoff a distributor giving alternating currents, and at the same time dividing the current out to several separate lamps or systems of lamps. Using this system of rapidly alternating currents, the "candles," when made with purified artificial carbons of great density, burn steadily and evenly until they are consumed away. Each is about nine inches long. They at first cost about sevenpence-halfpenny each, but can now be made at a lower price, and each lasts about an hour and a half.

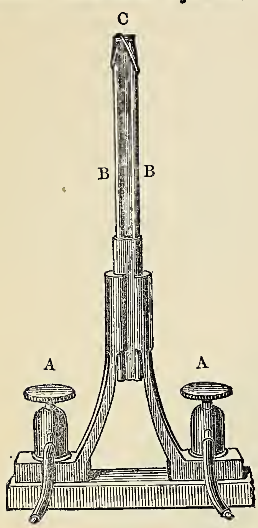


Fig. 57.—Jablochkoff's Electric-Light Candle.

There are numerous other forms of the electric candle and lamp now in use, but these will be described in full detail in a subsequent chapter.

In the preceding pages we have made a selection of some of the most important arts and manufactures, for the purpose of showing their gradual progress from a crude state to that of comparative perfection. In nearly all cases that progress has been slow, and in most instances has been delayed by the want of scientific knowledge in supplementing the practical. In the early state of many manufactures there was no earnest desire for improvement; manufacturers and their customers equally rested, and were thankful. But thanks to the spirit of modern enterprise and business competition such a state of things has long ago passed away. The modern manufacturer, either by choice or necessity, selects the best machinery, the most refined taste, and the most economical processes for producing his goods; failing this he would lose all chance of trade. Again, the educated eye, and the ever varying fashions and requirements of modern civilisation, constantly insist on progress, and these demands must be satisfied. It is true that we have not arrived at perfection, and never shall do in either arts or manufactures. But still it is in our power to continually aim at that end, and this is the great characteristic of our day.

J. W.

CHAPTER I.

COAL, AND COAL-MINING.

IN our introductory remarks on the Rise and Progress of the Sciences, Arts, and Manufactures, we have drawn attention to the early history of Mining and Metallurgical processes. In a country like our own, the subject is naturally of great interest, and, therefore, some further details will be afforded before entering on the practical part of the question. Britain is essentially a mineral producing country, and our chief sources of wealth lie in our extensive beds of coal, ironstone, limestone, and the ores of copper, tin, and lead, by which we are enabled to construct machinery for the purpose of converting textile and other raw material into articles of commerce.

We have already referred to the early history of mining in the days of the Saxons, Danes, and Britons, and also to the working of lead &c., by the Romans. When they left this country, and it fell under the sway of the Normans, the working of the mines was much neglected; at any rate, they seem to have been very unprofitable, and to have been principally in the hands of the Jews; but began again to revive in the reign of Richard II. Edward I., however, having banished this unfortunate race, mining was again neglected, till Edmund, the eldest son of this monarch, made some important alterations in the regulations of the tin-works of Cornwall by a charter, which was confirmed by Edward in the latter part of his reign. Indeed, it is from this time that the peculiar laws and privileges of the Stannaries (tin mines and mining in Cornwall) are chiefly to be dated. Mining infringed, in some instances, on property, and caused disputes, besides requiring indulgences not general; and thus arose causes not recognisable by the common law. In this way a peculiar code, springing from custom, took its rise; and though this, in some measure, existed before, yet it was not till this period that it was confirmed by royal charter, and enforced by subsequent acts of parliament. It was by this charter that the bounding of land to the purpose of tinners working on it, the duties to the Earl of Cornwall, and the coinage of tin, or stamping with the earl's seal were first established. Before the reign of Edward I., tinners worked in the earl's land only, paying him a fifteenth part of what they got; and they were not at all permitted to dig in sanctuary (consecrated ground), churches, mills, houses, gardens, and so on; and if, in working under, they chanced to subvert any house, or to damage a highway, they were obliged to make it good. When it became an object to search throughout any place, or person's lands, a court also to determine cases relating to the tin-works, became necessary; and this, adjudging under authority of, and according to, the code of laws before mentioned, was first established by Edward I., and is called the "Stannary Court." The privileges of the dukedom of Cornwall appertain only to the *eldest* son of the reigning monarch, who is also Prince of Wales. The present system under which the Stannaries are governed, and the revenue obtained from them, are matters of familiar interest to all our readers, and require no explanation.

In respect to mining for copper, Mr. Barlow observes—"Copper, of which so much is now sent from this (Cornwall) part of the country, was not an object attended to, till a comparatively late date, by the Cornish miners; even in tin mines, which, as they deepened, produced copper, as is often the case, and when they needed to raise tin ore, it was thrown by as of no value, going by the name of *poder*. Those who lived in later and more enlightened times, reaped the profits left to them by the ignorance of their forefathers; and this proves of what consequence it is to determine, if possible, the value of all the substances passing under the miner's observation.

"Copper, however, was probably worked at a remote period in Wales, at Parys mountain, which, indeed, is supposed to derive its name from the Celtic word *praas*, brass, or precious metal; and this would offer a proof of its having been worked by the ancient Britons. It was not, however, attended to, or at least not well understood, in England till the reign of Queen Elizabeth, who paid great attention to the mines of the kingdom; and, by granting great privileges to Daniel Haughsetter, Christopher Schutz, and other Germans, whom she invited into England, commenced and established the highly valuable and important business of finding and purifying this useful metal. To these two foreigners is owing the flourishing state of our brass manufactures. In this reign (Elizabeth's) Parys mine was granted to patentees, but was not worked, at least to any advantage, for a century and a-half."

We thus see that, despite the great and rapid advances made of late years, mining in its early stages, in respect to tin and copper at least, is practically of modern origin. In fact, like many other branches of manufacture, that of

metallurgy was kept back from a twofold cause —the want of demand for the articles that might be produced ; and, in the absence of this demand, a want of stimulus, that an enlarged production would have engendered in improved modes of working, &c.

We shall presently have to call attention to the geological distribution of coal and minerals; but, as we now deal only with general questions, we may remark that, practically, the coal and metal-bearing districts of the British islands are confined to England and Scotland ; although Ireland is rich in, but almost unworked for, both. The line of mineral-producing strata in Scotland and England follows a long range of hills, extending from nearly the Grampians in North Britain, to the Land's End in England—almost invariably on the west of the island, as in Lanarkshire, Lancashire, Devon, and Cornwall, with Wales on the extreme west, but branching eastward towards Edinburgh, in Scotland; Northumberland, Durham, Yorkshire, Shropshire, Derbyshire, and Northamptonshire, in England ; and associated often with mountains of limestone throughout the entire district. In the south-west of England, however, no coal is found. It is the locality of tin and copper; the latter being largely sent thence to South Wales to be smelted.

Throughout the whole of the districts we have named, the importance of coal to us, nationally, commercially, and socially, will more fully appear if we briefly glance at the industrial occupations carried on adjacent to the different seams, beds, or mines of the mineral. Taking Glasgow, and its surrounding towns and villages, we have an immense production of cotton goods ; dyeing, bleaching, and calico-printing ; iron-smelting ; iron ship-building; a great variety of other metal works, chemical manufactures, &c., &c. From the south of Lanarkshire, in which that city is situated, we have an entire break in manufacturing industry, until we reach Carlisle ; and in this interval, of about eighty miles at least, no coal and no industrial processes, comparatively speaking, are to be found. A person may travel for many miles on the railway, and scarcely see a sign of civilisation. Another mineral and manufacturing break occurs between Carlisle and Lancashire, when a fresh coal-field of enormous extent gradually appears ; and, at last we reach Manchester, the centre of a large district, and of the manufacturing activity of this country, the productions of which are too well known to require enumeration. Eastward, thence, we have the Yorkshire district, with its flourishing towns—as Sheffield, Leeds, &c., &c. —all on coal-fields ; to the north of which lie the Durham and Northumberland beds, so noted for their excellence of quality, and of the utmost importance, as bituminous coals, for the manufacture of gas ; and also for the manufacture of glass, and other processes carried on at Newcastle and neighbouring towns. South from Manchester, we enter the extensive Staffordshire and adjacent fields, over which iron-smelting, the potteries, the manufactures of Birmingham, &c., &c., are carried on. Diverging westward into Wales, we have the most extensive iron and copper-works—a district bounded south by the Severn, and west by the Irish sea.

Now, all these scenes of commercial activity are *on* the surface of the ground, beneath which the coal abounds ; and it is the readiness and cheapness with which the coal is there obtained, that engenders the commercial occupations to which we have briefly alluded. The first glance, therefore, will suffice to place the coal question in something like a proper light before our readers.

Of recent years, much alarm has been created in respect to the length of time that we may expect our coal-supply to last ; and speculations have been rife on the subject. Sir William Armstrong estimated, in 1862, with the then consumption, that our fields would be practically exhausted in 212 years. A work now before us, dated 1828, sums up all the estimates then made by living geologists, and assigns 2,000 years as the period, the conclusion of which shall witness the end of our coal supply. The real fact is, that we have far too few data to afford any rational ground for a just conclusion. It would be naturally expected that the coal-bearing strata of this country had not only been well investigated, but accurately estimated. But such is far from being the fact. Take, for example, the following. The Boghead coal, being the sole source of paraffin by Mr. Young's process, was supposed twenty-five years ago, to be limited to the neighbourhood of his works, at Bathgate, Edinburgh, or nearly so. Now it is found that a bed extends all the way to Airdrie, a distance of twenty miles, at least, in length ; and, consequently, it has been opened out to such an extent, to produce paraffin, as to make the oil, with petroleum (of American origin), frequently a complete glut in the market, and unsaleable from its abundance. But, apart from what can be obtained in this country, we must not forget that Ireland, as already stated, possesses extensive fields of coal, hitherto literally untouched. Giving results on this subject we have arrived at after due inquiry, and some personal knowledge of the subject, it may be stated that Leinster possesses an extended coal-field of the anthracite, like that produced in Wales. Near Dublin there is much bituminous coal. The Munster field occupies parts of Clare, Limerick, Cork, and Kerry; and is the largest in the United Kingdom. There is a small field near Tipperary ; and Ulster possesses three—one in Tyrone, another in Monaghan, and a third at the north of Antrim, near Ballycastle. The Connaught field is extremely rich, and is accompanied with immense quantities of ironstone, that is also found in the Leinster field. These sources of mineral riches are almost entirely undeveloped ; but will, doubtless, at some future day, contribute largely to the prosperity of the country. But in England, during 1880, several new seams of great value were discovered, the existence of which had never been suspected. Hence any speculations in respect to the time our coal supply may last, are visionary and futile.

We might enter still more fully into this subject, and point out how petroleum, peat, &c., have lately been used in place of coal for heating purposes with much success, and even economy, in raising steam for manufacturing purposes, locomotion, &c. ; but these questions hardly come within the scope of this work, which is rather to consider, explain, and enforce the applications of science, than to speculate on their possible extent and availability. Many artificial combinations of coal, peat, &c., have been made and sold, as a substitute for coal, under the name of "patent fuel," &c. ; and much attention has, of recent years, been devoted to the production of this, and similar substitutes, for coal itself.

We now briefly turn to the geology of the mineral beds, or strata ; and this is the question that has much relation to the application of chemistry, especially in respect to smelting operations. For the present we shall confine our remarks to such points as relate to the geology of coal.

Immediately over the Devonian or Old Red Sandstone rocks, we find what are called the *carboniferous* or *mountain limestone* beds or rocks, that, as they crop or rise out of the surface of the earth, produce such pleasing effect of hill scenery, common in many parts of the midland and northern portions of England, Scotland, and Ireland. Superimposed on these, lie what are called the *coal measures*, strata or beds, that afford the invaluable fuel from which they derive their name. In many parts of the kingdom, but especially in Scotland, from Ayr, through Glasgow, to Edinburgh, coal, iron, and limestone are found in immediate succession—a circumstance of the utmost value in iron smelting, for which coal as fuel, and limestone as flux, are so abundantly required. In respect to the distribution of coal in our islands, we have already alluded, in general terms, when attempting to show its importance in localising and centralising industrial occupations. Professor Ansted, the celebrated geologist, more particularly describes the coal distribution in these islands, and Europe generally, as follows :—

"Although coal is very widely spread over the earth, and exists in some districts in enormous quantities, these are still so limited, and their value depends so much on geographical position, that the actual use of this mineral as a fuel is greatly limited. . . . . On the east side of England we have the great Northumberland and Durham coal-field, with half a million of acres of workable coal, approachable in various places, along an extensive coast-line, with several good ports, admitting of the best and cheapest transport. In South Wales there exists a yet larger area, in which thicker and equally valuable beds can be worked ; and there, also, the coasts presents a number of convenient ports, from which the coal can be shipped. In the interior, a vast tract in Yorkshire, Lancashire, Derbyshire, Staffordshire, and Shropshire, larger in extent than the other two districts together, is not only adapted to supply the interior of England ; but, by means of railroads, competes successfully in the metropolis, even with the better coal conveyed by sea from the north. In Scotland, the valley of the Clyde is equally rich, and scarcely less important ; while in Ireland, each province possesses coal areas which are now but little worked, but which may henceforth prove of great value. On the continent, Belgium is especially rich ; France and Germany possess stores of mineral fuel, the former especially, of great extent, though placed far in the interior. Spain has large and excellent beds—those in the Asturias not unfavourably placed for present use ; while Russia is provided with this, in addition to her many sources of wealth."

We need scarcely remind our readers that, in many parts of Asia, especially in India and Japan, coal is abundant. It has also been very recently discovered in Tasmania, New Zealand, and Australia. An eminent series of authorities, in respect to American coal-fields in the United States, remark :—

"Next to England, the United States of America are the great depôt of coals. In that country there are four vast areas, covering, it is computed, between 60,000 and 70,000 square miles. The capacity of the Pennsylvanian mines is set down at 20,000,000 tons a year. In Maryland, the coal used by the Cunard line of steam-vessels, lies fourteen feet thick, and fifty miles long. Professor Smeaton estimates the seams in nine counties of Missouri, to contain 38,000,000,000 tons of capital fuel ; and another authority puts the supply as sufficient for 3,000 years, if 100,000 tons were mined per day. Professor Rogers calculates the Illinois coal measures at no less than 1,277,500,000,000 tons —a quantity six times greater than that contained in all the coal-fields of Great Britain, and sufficient, he thinks, to last for 100,000 years ; while Pittsburg boasts that she has seams around her containing not less than 55,516,430,000 tons." Our Canadian possessions, New Brunswick, Nova Scotia, &c., all afford coal in more or less abundance. But later researches, especially in regard to the United States, have greatly increased the estimate here given.

Even those who are indifferent to scientific considerations cannot help being forcibly impressed with the immense amount of light, heat, chemical and mechanical force, that has thus for ages been locked up in the bowels of the earth, and, comparatively speaking, but recently discovered. But the discovery of the uses to which this mineral may be applied is, as yet, but opening out ; for, until very lately, heat and light, in the form of fuel and gas, were the only economic results at which man had arrived in the use of coal. Petroleum, paraffin, aniline dyes, &c., &c., are all of an age less than thirty years ; indeed, far less, if we confine our attention to their extended use for economic purposes ; and scarcely a month passes but some new mode of utilising coal is found out.

On the change of vegetable matter, in remote ages, into coal, we cannot do better than quote Professor Ansted, who, in the following obser-

vations, presents us with a view of the chemical characters of the plant and its fossils. He observes—"The change that has taken place in producing coal from leaves, wood, stalks, or moss, is very considerable, and seems to have required either the lapse of a long period of time, or some chemical action of a peculiar kind. The component parts of all vegetables are chiefly carbon, oxygen, and hydrogen; but a considerable part of the two latter elements is in the state of water, and a certain per-centage of earthy matters, and the alkalies are also present (nitrogen, we may add, is a variable constituent of some coals). The water is sometimes 90 per cent. of the whole plant, but generally, in wood, it forms from 18 to 50 per cent. After a time, by pressure and exclusion from the atmosphere, this water is to a great extent got rid of; and the carbon, if unable to combine with oxygen in the natural progress of decay, is preserved for an indefinite period, together with the earthy and alkaline ingredients. As time advances, further changes take place; the external form becomes altogether lost, and even the texture is confused: but in this state, again, wood can remain for a very long time without further alteration; and if then exposed to the air, it forms the imperfect fuel called *lignite*. When, however, either by the influence of time or chemical action, a further change takes place, the proportions of the gases, and also of the mineral ingredients, are found to alter essentially; so that while, in pure woody fibre, there is about $52\frac{1}{2}$ per cent. of carbon, 42 of oxygen, and $5\frac{1}{2}$ of hydrogen—the proportion of ashes being less than 1 per cent.—peat is found to contain 50 to 70 per cent. of carbon, 20 to 25 of oxygen, and 10 to 20 per cent. of ash; while lignite, with about the same proportion of carbon, has much less ash, and 30 to 36 per cent. of oxygen. Lastly, coal, when of good quality, has from 80 to 90 per cent. of carbon, rarely 10 per cent. of oxygen, and less than 5 per cent. of ash. In all these cases the proportion of hydrogen remains; but in wood, peat, and lignite, it is combined with part of the oxygen, in the form of water; and in coal, instead of the oxygen, a part of the carbon is combined with the hydrogen, forming carburetted hydrogen gas. This composition, with certain differences in compactness and uniformity of texture, is among the characteristic peculiarities of coal; and the more perfectly these conditions are fulfilled in any mineral fuel, the more this material becomes available as real coal. It is not unlikely that the gas thus formed occupies the place of water in the cells of the plant when in its new and mineral condition. At any rate, it is certain that, on the removal of part of a bed of coal, the gas issues very freely from these pores in large quantity, and is occasionally so abundant as to be the source of extreme danger. Thus, then, the nature and history of coal has been traced, and we see this substance reduced to its true position as a mass of vegetable matter, originally bedded with clay and sand, and forming a component part of the mineral substances composing the earth's crust."

Thus far for the production of coal from vegetable matter by chemical and other causes that in course of time operate. We now turn to consider its position in the crust of the earth; the nature of those beds; and the means adopted for the removal of coal to the surface.

The external aspect of a coal district is by no means inviting. As a rule, collieries are in waste-looking places, the surface of the ground being, most frequently, barren and desolate; so that riches below have to compensate for their absence above ground. Occasionally, however, the reverse is the case; and pre-eminently so in respect to Scotch coal mines, many of which are situated, together with iron mines, in the most picturesque and beautiful scenery. A pine wood frequently surrounds and hides the entrance to the pit. But the circumstances that are concomitant with coal-mining, are the production of much smoke, fine dust in clouds during dry weather, and a variety of other effects, all militating against a long preservation of picturesque beauty in localities at which coal, and, indeed, any mining, is carried on.

The different species of coal are confined to individual localities. The bituminous variety is that most in request for house coal, and the production of coal gas. Cannel or parrot coal is the most valuable for gas-making. It is afforded, perhaps, best near Lesmahago, a few miles from Glasgow, but is also met with elsewhere in the Scotch field; also at Wigan, in Lancashire, and in some portions of both the Yorkshire and Derbyshire beds. Jet may be considered as a fine variety of cannel. Ordinary bituminous coal abounds largely in the Northumberland and Durham fields. It burns with much flame, being rich in volatile hydrocarbons; readily ignites, cakes together in masses, and is altogether by far the best coal for domestic use. A good specimen will yield as much as 38 per cent. of volatile matters, and only about 5 per cent. of ash. Of the same kind, but inferior in quality, are the coals now so largely got to compete with Newcastle coals, and carried by railway from Yorkshire, Staffordshire, Derbyshire, and some parts of Wales. While this coal burns freely, it yields more ash than that of the eastern beds; it does not cake, but throws out much heat. From being cheaper than Newcastle coals at first cost, a great amount is now consumed in London; yet, to use a common saying, the best ("Newcastle") coals are the cheapest in the end.

Another kind of coal, intermediate between the bituminous and anthracite, is that known as steam coal. It burns without smoke, containing but little volatile matter; is very hard, and compact. It is useful and economical in raising steam under boilers; and may be used for the manufacture of iron. It contains from 80 to 85 per cent. of carbon. Various parts of Wales afford this kind of coal, which is now becoming of large use for the purpose already mentioned.

Anthracite coal is that which contains the greatest quantity of carbonaceous, and the least of volatile matter. At the present time, the

supply is entirely drawn from South Wales; but the southern portion of Ireland contains an extensive field, as we have already stated, at p. 2 *ante*. Generally, the coal is very hard, burns slowly, and has a great evaporative power. Hence its use for raising steam, smelting iron, and for other uses where intense heat is required; that is, stimulated by a powerful draught. One pound of the best Welsh anthracite coal will evaporate double as much water as the best bituminous Scotch coal, and about 25 per cent. more than the best ordinary steam coal.

Another variety of "coal," called the Boghead, of which we have already briefly spoken, may be named. Its peculiarity is, that it yields an enormous amount of volatile matter (about 70 per cent.), with a great quantity of ash, that sometimes reaches nearly 40 per cent. It is from this substance that Mr. Young first obtained, to any extent, the paraffin, oil, and solid, with the production of which his name has long been identified. As a fuel it is valueless, from its deficiency in respect to the possession of solid carbon as a permanent constituent.

We shall omit all notice of lignite, peat, and analogous substances, because, up to the present moment, they have not attained any commercial value. It is possible, that peat, when obtained from localities adjacent to any large works requiring much fuel, may be worked with advantage; but its bulk, compared with its heating properties, is so disproportionate, as to cause great cost in carriage; and hence an approximation to, if not always exceeding the expense of coal, both being supposed to be used at equal distances from their respective sources.

At the same time, it is a matter of great importance to utilise our peat bogs. A very large proportion of Ireland is covered with them; and they occur in or near the mountainous districts of Great Britain and Wales. The enormous abundance of this material, therefore, offers great inducements for a close, but liberal, experimental investigation into the economic value of this article. We may encourage any of our readers by referring to the example of the Cleveland district in respect to iron ore. For a long time it was completely neglected; and, from circumstances we shall eventually explain, considered comparatively valueless. But, during the last twenty years, intelligent applications of chemical science have so developed this field, that it now stands second to none in importance in our island. Similarly, we may hope that means may yet be discovered that shall take away the reproach of "waste" from even a peat bog. Chemically, we know such to possess much of valuable materials; but practically, we have, as yet, failed to extract it.

The geographical position of coal in our own islands, and in Europe generally, has been already descanted on at p. 2 *ante;* but its local position in respect to strata, angle of deposition, &c., &c., have yet to be considered.

And first we have to notice that coal-beds generally have been subject to severe disturbance or dislocation in most parts of our islands. At times they are level; but very frequently they present a great curve; and proceeding from a great depth beneath the surface, they eventually "crop out;" that is, rise to the surface of the ground. We have seen frequent instances of this in the Yorkshire and Scotch beds. "The beds of this material, as they exist now, include a singular variety of appearance, magnitude, and condition, being sometimes perfectly regular over wide districts, in nearly horizontal strata, and, as already explained, of various thicknesses. Sometimes several hundred seams will be found, all parts of the same great series, and separated by thousands of feet of sandstone and shale; while, occasionally, there are only a few thick or thin beds, associated with masses of boulders (irregular masses of stone, that have been brought by a current, or other force, from a distance), and barely covered up with thin deposits of little importance, and doubtful age. In one place we find the uniformity of certain seams so great, that in sinkings made through the strata at distant points the order can be recognised, and the particular part of a known field at once determined; but, on the other hand, it may happen (though not often in England) that, in the same mine, the thickness of a bed is so variable, and the coal itself so irregular, that it would be impossible to imagine any relation between two not very distinct points in the seam, if the workings were not continuous, and the mineral from one point actually continued to another. A seam of coal sometimes terminates gradually, by thinning into a mere line; and sometimes abruptly, by a similar break; while occasionally it becomes split asunder, and the upper and the lower parts thin away, and are almost lost. The former case—that of gradually thinning out—shows a lens-shaped condition of the coal (bed); while the latter, sometimes called a 'horse,' shows the intrusion of a mass of clay or sandstone, of the same shape, between two parts of a coal seam. There is also, sometimes, an abrupt termination of the bed, either marking some local disturbance by which the coal has been removed to a distance above or below, or the result of an ancient denudation (uncovering), by means of which the coal was formerly partly worn away by exposure, either being pared off by the direct action of the waves, or undermined and removed when soft underlying clays have been acted on at the foot of a cliff. Besides these cases, however, the coal is sometimes suddenly curved up, and disappears for a time, as if an obstruction had existed at the time of deposit, and the vegetable mass had collected round it."

Various causes lead to the alteration of the horizontal form of coal strata. In Fig. 58 we have an illustration of one, elevated at an angle with the horizon; and at some parts the coal (shown by dark lines) crops out to the surface.

But, at times, the strata is disturbed by subterranean forces in an extraordinary manner. Some portions are raised so as to reach the surface of the ground, and then crop out, descending, on either edge of the seam, to a considerable

depth below the surface of the earth. An illustration of this is given in the following cut (Fig.

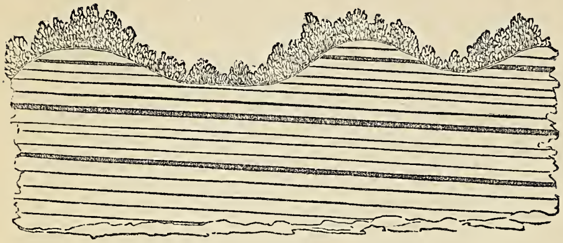


Fig. 58.—Horizontal Strata of Coal.

59), where we notice that the beds, or strata, have assumed a basin-like form raised at either end, and depressed at the middle. Many coal seams are thus circumstanced, and numerous portions of our coal districts give evidence of the fact, on close examination.

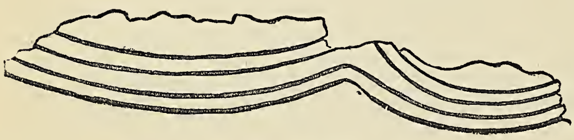


Fig. 59.—Basin-like Strata of Coal.

A *fault* in a coal mine is aptly illustrated by the following cut, (Fig. 60). It consists in a disturbance of the continuity of one or more seams, by which one portion is raised, and the other depressed; so that, in fact, the seam is completely divided; and between the divisions is a crevice, as shown in the section, at *e e*. Now, it is plain, that, supposing the cut to illustrate nature actually (as it does), *a* and *a*, *b* and *b*, *c* and *c*, and *d* and *d* must have, at one time, been continuous seams, that have been dissevered.

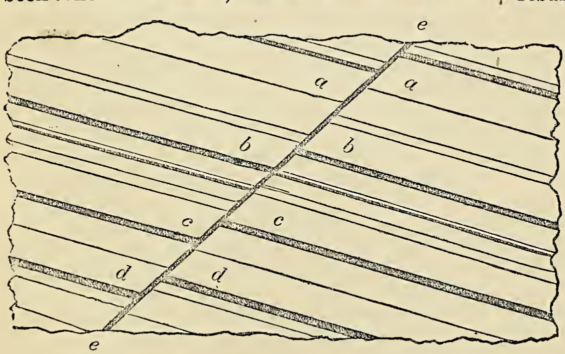


Fig. 60.—Faults in a Coal Mine.

The dip, or inclination with the horizon, is the same on both sides of the crevice; but it is evident that the elevation above or below the surface of the ground, differs between the two parts of the seam so greatly, that the miner will at last have his labours suddenly terminated, whether he works on the left or right divisions, on his reaching the crevice. Experience has taught, to a certain extent, a remedy for this evil, or rather an average chance of regaining the seam. It is as follows:—"The important point to observe is the direction of the fault; for if that incline, as in the case before us (see preceding engraving), to the left, the beds dipping to the right, it will follow that the angles made by any one of the beds, in its two positions (before and after fracture) with the fault, will be two obtuse angles; and thus a rule is obtained for following the seam. The practical rule is, that if the fault make an angle less than a right angle with the bed of coal, the coal must be looked for at a lower level on the other side, being *downcast* in that direction; if, on the contrary, the angle be greater than a right angle, the coal will be at a higher level, or *upcast*. It must be observed that the distance to which the coal is heaved is not at all indicated by the nature or direction of the fault."—*(Ansted.)*

This is one of what we may call the geological difficulties in coal-mining; and that often causes much loss of capital to overcome, besides stopping the use of that already invested in the mine. It is, indeed, impossible for those unacquainted with the obstacles incident to all kinds of mining, to estimate the amount of skill, perseverance, courage, and capital required in all cases for success. But, occasionally, with the exercise of all these qualities or conditions, failure alone results. An instance of this kind was related to us, some years ago, by a friend, in connection with mining for lead. An adit (that is, a kind of horizontal tunnel) had been driven into the side of a hill, with the expectation of soon finding a lode or vein of the metal. Many weary days and months were passed with no result, except apparent loss of money. It was, at length, determined to give up all further pursuit on a certain date. The day previous (we believe), a vein of rich ore was discovered; and thus, by a fortunate occurrence, the capital so long expended, and seemingly wasted, was soon repaid, and the mine became highly productive.

But another, by no means uncommon, and a most serious, difficulty is met with in coal-mining. To explain the nature of this, we may observe, for the benefit of those ignorant of the principles of geology, that although we can, to a very great extent, satisfy ourselves as to the exact order in which each of the strata has been produced and deposited to form the external crust of the earth—say from the old red sandstone, the mountain limestone, coal measures, and so on, till we get to very recent strata, as those of chalk, &c.—still, all these, but especially the older strata, are liable to irruptions, that have occurred, and still may occur, of melted

rock and earthy matter. Urged by enormous force from below, this melted matter is driven through such strata, and forms banks or masses called *dykes*, that effectually divide the coal measures, &c.; and are far more serious, in their results, than the *faults* just described. For instance, the crevice or partition, *e e*, in the preceding engraving (Fig. 60), is generally filled up by some soft matter—as clay, pounded earth, crystalline bodies, as quartz, aragonite, &c., &c.; and sometimes this crevice or division is barely perceptible. Not so with a dyke. Its material is of the hardest nature, and requiring the hardest tool to get through. But often its thickness is so great as to entirely prevent the possibility of boring through it, when no other course is open but to begin, *de novo*, the sinking of a shaft, and other mining operations, on the other side, which involve at least an equal outlay as may already have been expended on the worked seam, but with the utmost uncertainty as to whether the seam will be readily met with. Partly of this kind arose the enormous difficulties in boring Mount Cénis, for a tunnel for the railway between France and Italy. In more than one case, in this country, contractors have been utterly ruined in forming tunnels through hills and rocks, for railway and other purposes, owing to the discovery of a dyke, the existence of which had been previously unsuspected. Some idea of the hardness of the material may be gained, by those of our readers who are unacquainted with the nature of the substance thus met with, when we state, that it exceeds that of granite; and is often constituted of whinstones (used for mill-stones), basalt, &c.

Although it does not follow that dykes are always resulting from the irruption of igneous matter (and, indeed, geologists, at this day, are greatly qualifying views formerly held in respect to the cause of many of what are called *igneous rocks*), still, instances have occurred in which it is impossible not to doubt that highly heated and melted matter have been their cause. A case of this sort is seen in the dyke met with in Durham, which is from ten to twenty yards wide, runs at least seventy miles, and of unknown depth. The effect of this irruption of the heated matter on the coal, is thus described by Mr. Witham (as quoted by Dr. Ansted):—"Within fifty yards of the dyke the coal begins to change. It first loses the calcareous spar (we presume aragonite), which occurs in the joints and faces; and also loses the quality for burning. As it comes nearer it assumes the appearance of half-burnt cinder; and, approaching still nearer the volcanic mass, it grows less and less in thickness, becoming a pretty hard cinder, and only two and a-half feet thick; eight yards further, it is converted into real cinder; and more immediately in contact with the basalt (the melted matter that caused the dyke, and constitutes it), it becomes, by degrees, a black substance, called 'swart,' resembling soot caked together—the seam of the coal being reduced to nine inches in depth (thickness). There is a large portion of iron pyrities (a combination of iron and sulphur, that causes the yellow and golden appearance frequently seen in coal), lodged in the roof of that part of the seam that has been reduced to cinder. On each side of the dyke, between it and the regular strata, there is a thin gut or core of clay, about six inches thick, which turns the rain-water on the rise side, and forces it to the surface, forming numerous springs as it travels the country. The coal deteriorated by this greenstone dyke, is twenty-five yards of bad, short coal; sixteen yards of cinder; and ten of sooty substance."

The preceding account of this dyke is exceedingly interesting, because it gives an evident clue to the formation of masses of our hardest rocks in nature (although the term rock is not strictly, according to geological science, attributable to granite, basalt, &c.) The subject is also not without interest in respect to its chemical relations; for an ingenious speculation has been made, that the extensive petroleum or rock oil deposits, or rather streams, in the United States may have arisen by coal distillation, caused by a general high temperature of rock lower than the carboniferous series, or by the irruption of such igneous matter as we have been describing, which, acting like the furnace on the retort of the modern paraffin distiller, caused an evolution of vapour, afterwards condensed by upper and cooler strata, and at last assuming, by its gravity, a liquid condition. In this state it has been held in a basin, until, by boring, it has—Artesian-well fashion—forced itself upwards out of nature's subterranean store house for the use of man in our day; doubtless, greatly remote from the date of its production.

From the preceding relations, we cannot help perceiving how many are the conditions that have tended to bring to our feet the bed of coal that supplies us with fuel, heat, chemical and mechanical action being prominent. A lump of coal hides in itself the history of ages. Once the flourishing plant, absorbing heat and light from the solar rays, it lost its vitality, and became buried for periods, which, as far as we can understand from present appearances, must far exceed the limits that we fix to time. The vital force of the plant was not lost—it was but disguised; and now we draw from the remains of the ferns, and other members of the vegetable kingdom, the light that renders night day; the force that drives our engines, in factory, on sea, river, and road; and utilise that which, but a few centuries ago, was despised as the dust and dirt of the earth.

We have so far noticed the various kinds of coal, the peculiarities, geological distribution, and other particulars relating to it, as exterior to, or simply resident in, strata. We may now briefly relate the methods adopted in winning the coal—that is, arriving at the seam; the means of removing it from the mass; of bringing it to the surface, and other questions relating to the practical part of coal-mining.

It is evident that many circumstances contribute to aid or hinder the enterprise of the miner, besides those already enumerated, and which are beyond his control. Of course, in

this country, where the direction, dip, position, &c., of most of our seams are so well known, these difficulties are minimised. If a seam crops out to the surface, then nothing is required but to break it up, and cart it away. But this is so rare a case, as to be, practically, never met with to any valuable extent.

The universal method is to sink a shaft; before doing which, however, boring is had recourse to, so that some knowledge of the depth from the surface, thickness, dip, &c., may be obtained.

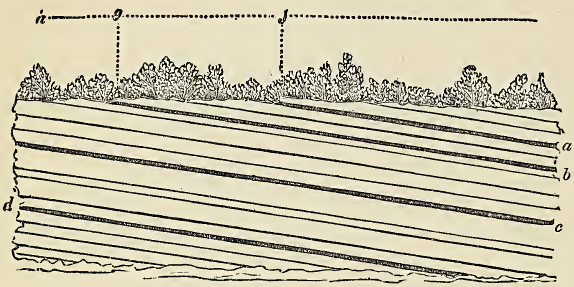


Fig. 61.—Coal Stratification.

In the preceding cut (Fig. 61), some idea of the nature and importance of such particulars will be gathered: *a*, *b*, *c*, may be considered the lower ends of seams, of which *a* and *b* crop out at *f* and *g*. The lower one, *c*, extends, at the same angle or dip, to a much greater length and depth beneath the ground; whilst *d*, although at the same angle or dip, is still far from the surface, and at its end may not crop out for many miles, if at all. Now, of course, every foot of descent from the surface adds to the expense of making the shaft, pumping, and other requirements of mining operations. But by boring at different points in the direction of the beds, it may be easily discovered what the rate of dip is in a certain number of feet or yards; and, in numerous cases, an approximation may be made towards that point at which the seam crops out, provided the dip is regular, which is, of course, simultaneously ascertained. Hence one desirable object in coal-mining may be, to a certain extent, arrived at—namely, to minimise, as near as possible, the depth of the shaft; the after operations, as we shall shortly perceive, are easily accommodated to most circumstances: it is therefore of great importance to save, as far as possible, all unnecessary expense at first starting.

One great error, and that which has caused the loss of hundreds of lives, is sinking but one shaft to a mine, or in making one large shaft act the part of two, by dividing it with brattices. Some years ago, 200 miners lost their lives in the Hartley colliery, in which was one large shaft divided into two, in the manner just referred to. The beam of the engine over the shaft broke, and, in its impetus, destroyed the frame-work of the shaft; and thus the colliers beneath were literally buried alive, or rather starved to death. Towards the end of 1866, within a few days of each other, the fearful explosion at the Oaks colliery, in Yorkshire, and one near Hanley, in Staffordshire, caused the loss of 500 lives; and had but one entrance to each pit existed, it would have most effectually barred any efficient aid being rendered, if it could have been of any avail. We need not, however, multiply instances of the kind, that have since resulted, through neglect of this precaution; for, all our readers who are familiar with the coal-mining districts know, the single-shaft system, or one shaft divided by brattices, was once all but a universal rule. It is true that two shafts involve double expense, and this, at times, would almost bar the working of the mine; but still we could point to many mines, in which not only is an enormous capital involved, but an immense revenue obtained; and, in case of an accident to one shaft, the working of the mine must be entirely stopped until it is repaired. Hence, independent of any question of humanity, self-interest should direct such a course.

The chief sources of expense in sinking a shaft arise from the variable nature of the earth, rock, &c., to be passed through; the irruption of springs, which necessitates constant pumping, and greatly impeding the work; and the frequent occurrence of a kind of shifting sand, too soft to retain its place, and therefore continually falling in. The latter circumstance has similarly been extremely ruinous to many contractors in constructing railway tunnels, and is almost a worse evil than solid rock. The operation of keeping out water is called tubbing, and literally consists in making the sides of the shaft water-tight by wood, stone, or metal. The old method was that of fixing planks on each side of the shaft, as close and firm as possible, much after the fashion seen in constructing the sewers of our streets, so as to protect the men working at a depth below the surface of the roadway. Such a plan is called plank-tubbing. In place of this, and far more effective and permanent, is solid wood-tubbing. Another method, now commonly used in making the foundation of bridges, &c., and therefore familiar to most of our readers, is that of using cast-iron cylinders or segments, which, being bolted together by flanges, form a continuous pipe, that will last for a long time, provided no mineral substance capable of acting on the metal is present in the water. But as various saline solutions are generally met with in all coal-mining districts, this plan may eventually fail by the destruction of the iron; and hence the pit would become flooded with water.

The following account will give the unpractical reader some idea of the difficulty in sinking a pit for coal. It relates to one of the mines in Northumberland:—The diggers first penetrated through clay to a depth of 102 feet; and then through sandstone, forty-two feet; then they came to a seam of coal only eight inches thick; this passed, they dug successively through

twenty-nine different strata, or layers of sandstone and shale, varying from forty inches to thirty feet in thickness, interstratified with eight seams of coal, from five to eighteen inches in thickness, and amounting to 418 feet deep; they then came to the chief seam of coal, nearly seven feet thick; next through fifty-two beds of sandstone and shale, interlying with nineteen seams of coal—the aggregate thickness of the whole being 503 feet: then they came to a seam about three feet thick; and, lastly, through fourteen alternations of stone and coal, having a thickness of eighty-two feet. The result, then, was this—that, in digging to a depth of 1,158 feet, they passed through 125 different strata, of which thirty-two were coal, varying from five inches to seven feet in thickness.

The depths of coal mines in this country vary greatly, from causes already explained, when we were describing the preliminary steps to sinking a pit, and the dip or inclination of the beds. Some pits are not more than fifty feet deep, whilst others extend to 1,500, or 2,800 feet. In mining language, the depth is always reckoned in fathoms, of six feet; hence the last-named depth would be called 467 fathoms. Of course, the greater the depth, the higher the expense of raising the coal and miner to the bank-top, which is the platform that surrounds the mouth of the pit. The coal is raised to the top in a kind of a tub, or trough, called a corve, hooked on to the rope. The latter is flat, and about four inches wide by an inch thick. Formerly it was of hemp; but now generally of wire. It passes over broad pulleys, that hang by framework over the top of the pit; thence it is passed to a drum, that is caused to revolved by means of steam power. On a given signal below, the engine is started, and the corve, containing either coal or men, is raised to the top. A source of accident occasionally arises from carelessness on the part of the engine-driver, who, if he does not stop the engine at the right moment, may raise coals or men as high as the pulleys overhead, when the contents of the corve would be upset into the shaft—a result that, of course, would be instantly fatal to humanity. Very rarely the rope breaks, when similar results must occur; but all such chances of danger in coal-mining are trifling to those of which we shall have presently to speak.

The forms of winding engines for raising the coals, and for lowering and bringing up the colliers, of course, vary according to the requirements of the mine. In this country, where the amount to be lifted is enormous, an engine, with boilers, is fixed at the top or mouth of the shaft, with all the necessary gearing for the purpose already mentioned. In the engraving (see page 12), an ingenious method, the invention of Messrs. Appleby, of London, &c., is illustrated. It was designed for use in Spain, where many difficulties had to be encountered in regard to cost of transport, erection, and the absence of building materials. On the right hand side will be seen a locomotive engine, which takes the place of the large engines and boilers, employed at the surface of our large mines. In the centre of the cut is the winding drum, on which the chain or rope is fixed. This passes over one or both of two wheels shown at the top of the cut (Fig. 64), and descends into the opening of the pit immediately below, carrying the cage or corve to the bottom of the pit, or used for raising them.

A visit to a coal mine, especially a deep one, is an adventure that will quite satisfy persons unused to mines, or unconnected with them, at the first attempt. The descent is rapid; and, as daylight is speedily lost, an "Egyptian" darkness is soon experienced. On landing at the bottom, however, numerous objects of interest excite the attention of the stranger. The uncouth appearance of men and boys, the former black and half naked; the dingy appearance of the sides, bottom, and roof of the pit; a close, unpleasant smell; the flitting of lights to and fro; and, possibly, unless the stranger is cautious, a contact with a basket or corve filled with coal, and rapidly driven along to the bottom of the shaft—are all circumstances that remind the visitor of his exchange of the upper for the lower regions of the earth. In many places the mines extend in miles of galleries in all directions. A certain amount of monotony, however, results from too extended a visit to a coal mine; for, generally speaking, each fresh-viewed portion is but a repetition of that previously seen. The novelty strikes the stranger; but we question if many would repeat a visit to these lower regions, unless actuated by scientific or business considerations.

In reference to the different plans of working a coal mine we may refer to that eminent authority, Dr. Ansted. He observes as follows:—

"The methods of working adopted in England may be grouped into three, which, however, are often combined. These are—*first*, the pillar and stall, or bord and pillar, adopted in the Newcastle coal-field; *secondly*, the long-wall, as adopted in Derbyshire, and some parts of Yorkshire; and, *thirdly*, that employed in South Staffordshire for working the thick coal. Of these, the former is by far the most completely developed, and admits of the most perfect ventilation; but it is not so economical as the second. The third is only a modification, adopted when the coal is too thick to be got out by one level. The principles involved in each method are easily explained.

"In working by the bord and pillar, the coal is at first got from comparatively narrow galleries, parallel to each other, and through the coal on its rise; and others at intervals, intersecting them at right angles. Thus the whole of the seam of coal within the property worked, is reduced to large rectangular pillars between these galleries, the pillars being left to support the roof (that is, the top of the mine and seams, and which, but for this precaution, would, of course, soon fall in—a matter of common occurrence in worked-out mines, and often causing the subsidence of the ground overhead). The shaft being supported by sufficient coal all round, and the roads also protected in a similar way,

the mine is safely worked in this fashion; and afterwards, by cutting the pillars through, and, at last, removing them, replacing the coal, for a time, by stout wooden props, which are also ultimately removed, a large per-centage of the coal is got away; though, in most parts of the pillars, it is too much crushed to yield 'round' (large) coal. There is thus a considerable loss, and the roof is left to fall after the coal is removed, thus producing a broken hollow, like an inverted funnel—technically called a *goaf*—or else allowing the surface to sink in what is known as a *creep*. It frequently happens that the upper surface of the ground is also depressed.

"Of late years, all large mines have been worked in panels or divisions, shut off from one another by a sufficient thickness of coal, to prevent an accident from extending beyond one panel, and allowing of better regulation of the ventilation. When the great magnitude, and the importance of ventilation in a coal mine, are taken into account, the value of this modification will be felt to be very great."

We may here mention, that forming a "bord" consists in cutting out, by pickaxes, the lower part of a mass of coal from the seam. This is done to detach the lower portion of the seam from the rock, or another portion of itself. A "judd" is then made by picking away the sides of the mass; and thus, when both operations are completed, a mass of the coal is produced projecting from the main seam. It only remains to break this off; and this is effected by boring a sloping hole in the "judd," and filling it with gunpowder. A train or fusee is attached to this, which, on being fired, detaches the mass: or the coal is frequently removed by the action of wedges, in large fragments. These are then thrown into the corve, and driven on a platform, by a man and a boy, to the bottom of the pit; then to be hoisted above ground. Recent methods of working the coal by machinery we shall hereafter allude to.

Reverting to our quotation. "By the long-wall method, the whole of the coal is got at one operation, either by working from the shaft towards the rise of the coal, and making safe roadways through the fallen roof by strong, stone, continuous pillars, or by driving first to the extremity, and working the coal back towards the shaft, leaving the goaf or rubbish of the fallen roof behind, and neglecting to keep roads through the goaf. When the goaf is not dangerous from the pressure of gas, and the roof will admit of it, this method is economical and efficient, as the whole of the coal is at once removed on a long face, and is not subject to the partial crushing that takes place when pillars are left."

On this point we may, parenthetically, remark that goafs are not only dangerous, becoming frequently reservoirs of explosive gas (fire-damp), but have frequently proved the source of fearfully fatal accidents. Indeed, before the actual cause of an explosion is discovered, it is generally said (when likely from the position of the mine) that the men have broken into a goaf, the relic of former mining operations. Thus economy, or rather rapacity, in adapting the "economical" methods just referred to, has had the fearful results of filling churchyards and poor-houses, depopulating villages, making widows and orphans, and rendering the country, once rejoicing with life and prosperity, a waste, howling wilderness.

"The thick coal is worked, in South Staffordshire and the neighbourhood, in a very irregular mode. Small pillars are left at unequal intervals; and sometimes the pillars are removed; but, in all cases, there are walls of coal left, at moderate distances apart. The coal in the district is parted by thin bands of clay, but the whole is removed."

The following illustrations will give some idea of the method of forming a "bord" and a "judd." Fig. 62 presents a view of the pitmen

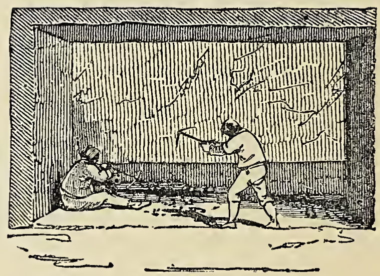


Fig. 62.—Pitmen forming a "bord."

picking away the lower part of a mass of coal, or of forming the "bord." Fig. 63 illustrates the method of producing the "judd," in which it will be observed that the two vertical sides of the mass are in course of removal.

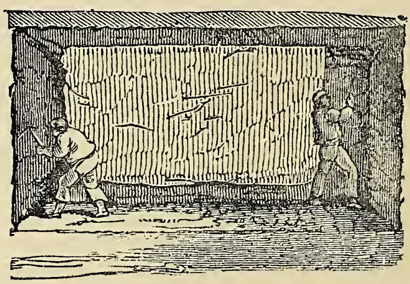


Fig. 63.—Forming a "judd."

We may here notice that the removal of coal from mines has a very singular effect, at times, on the upper surface of the ground beneath which the mine is situated, and to which we have already briefly alluded when describing the "bord and pillar" system of coal-mining. In many parts of the coal district, we have noticed its effect in depressing the ground. Often pits are produced that form ugly variations in the landscape. This falling-in of the earth, owing to the removal of the coal, has both

its serious and ludicrous aspects. In certain districts it bears the name of a "crowner in." One of these, for example, took place at Newton, about four miles from Stourbridge, in December, 1866; and it arose from the gradual falling-in of a "shaft," produced from the sudden subsidence of the earth in a comparatively limited area, and not, as is frequently the case, from an extensive superficial subsidence. The village of Newton is built on the Earl of Dudley's land, and in the vicinity of an extensive colliery, belonging to his lordship. For some time previously, the owner of a public-house had noticed that the ground on which his house was erected had been gradually subsiding; and he took the "usual" measures—cramping the house with iron rods, and buttressing it with trees, to lessen the damage of the building; evincing, in our opinion, as much coolness, or rather wilful blindness to danger, as may be noticed amongst the inhabitants of countries accustomed, or, perhaps, rather hardened, to the visitation of earthquakes. All his precaution proved of no avail; and, at last, one evening a hole was perceived in the back-yard. The alarming noise, consequent on the formation of the shaft (the local name for this narrow subsidence of the earth), was accompanied by an outgush of a gas, known, amongst the colliers, as "sulphur" (some form of sulphur-hydrocarbon that had long been pent up beneath); and this having come into contact with fire, it ignited. Of course the house speedily caught fire. Gradually, the back of the house, household goods, &c., &c., descended in the widening gulf; and, in little more than twelve hours, the "crowner in" had increased to a hole sixteen to eighteen yards across one way, and ten or twelve in the other, with a depth of about ten yards—the bottom of the rent being covered with great masses of rock rent from the sides of the hole. Fortunately, in this case, no lives were lost. We cannot refrain from stating, that, owing to such occurrences, we have frequently been nervous for the safety of some of our railways in the coal districts. We could point to scores of places over which the railway is carried, and under which the coal miner is undermining. We sincerely hope that time may not startle us with some fearful accidents, arising from causes which we have explained and illustrated by a special example. Only a short time ago great precautions had to be taken in the neighbourhood of Wednesbury, during a journey of the Queen to Scotland, to avoid the possibility of the accident to which we refer.

Before detailing the internal dangers of coal-mining, we may say a few words about the miners themselves, gathered simply from personal experience. Because they work beneath the surface of the earth, at "depths deeper than the grave itself"—because their work is laborious, irksome, dangerous, and filthy; badly paid for, considering the risks they run—they have, as a rule, been considered as all but the offscouring of the earth. We have mixed with, and been in the houses of these miners, for a period *en famille*, and cannot agree with such aspersions on a body of men, who, whatever their faults may be, are at least laboriously industrious. A collier's village may at one end be a scene, at times, of drunken disorder; but we have seen considerable portions of it a credit to religion, morality, temperance, and intelligence. Our pages are not the medium through which to convey special instances of the kind. They have already become matters of history; and there has been as much heroism shown in the coal mine as on the battle-field. Noble instances of this kind—connected with painful loss of life near Barnsley in Yorkshire, at the Oaks colliery, and at Talk-o'-the-hill, near Tunstal, in Staffordshire, during the explosions which took place in December 1866, within a week of each other—will be remembered by all who peruse these pages, and in 1880 some fearful coal mine accidents, further illustrated these remarks. We have addressed some hundreds of coal and iron miners, fresh from the pit, begrimed with dirt, on scientific subjects; and have found their attention quite as riveted and devoted to the subject, as if we had been addressing a "west-end" audience. On one occasion we were invited, by the owner of a large colliery, to address a number of his men, who were considered as the most lawless of the district; and were cautioned that we should do so at our own risk, in respect to apparatus, &c., &c., whether as regards theft or breakage. Having much faith in humanity, we accepted the invitation. The lecture-table was covered with apparatus; and when all was ready, about 250 miners, literally as black as coal, and just out of the pit, walked in and took their seats. At first the sight was by no means encouraging; and the imagination of our non-mining readers will not be over-excited if they apply all the description of the blackest pictures painted by poets to what then appeared before the lecture-table. The subject chosen was on "Heat," as one familiar in its applications to them all. For nearly two hours not a sound was heard amongst the men; they listened attentively to what was said, and seemed much interested in all the experiments. The concluding one was that of handling red-hot lead; one of the men was sent to the store of the mine to fetch the lead in a ladle; and on its being brought in, two more assisted to melt it. When red-hot, the two brought the ladle, out of which we threw the lead with the naked hand, moistened with ammonia. The result of the experiment was that of producing the utmost enthusiasm. The cheers shook the place. We had abundance of help to pack up the apparatus; the boxes containing which were speedily hoisted, with brawny arms, on to the top of the carriage conveying us: however, just at starting, the coachman drove into a rut, that nearly upset the conveyance; and, in a moment, these men rushed to our rescue—lifted carriage, boxes, and ourselves bodily out of the hole, and bid us go on our way rejoicing, with a hearty cheer.

We have related this incident because of its having been personally encountered in a district known for savage debauchery, tempered with intelligence; and that our general readers may

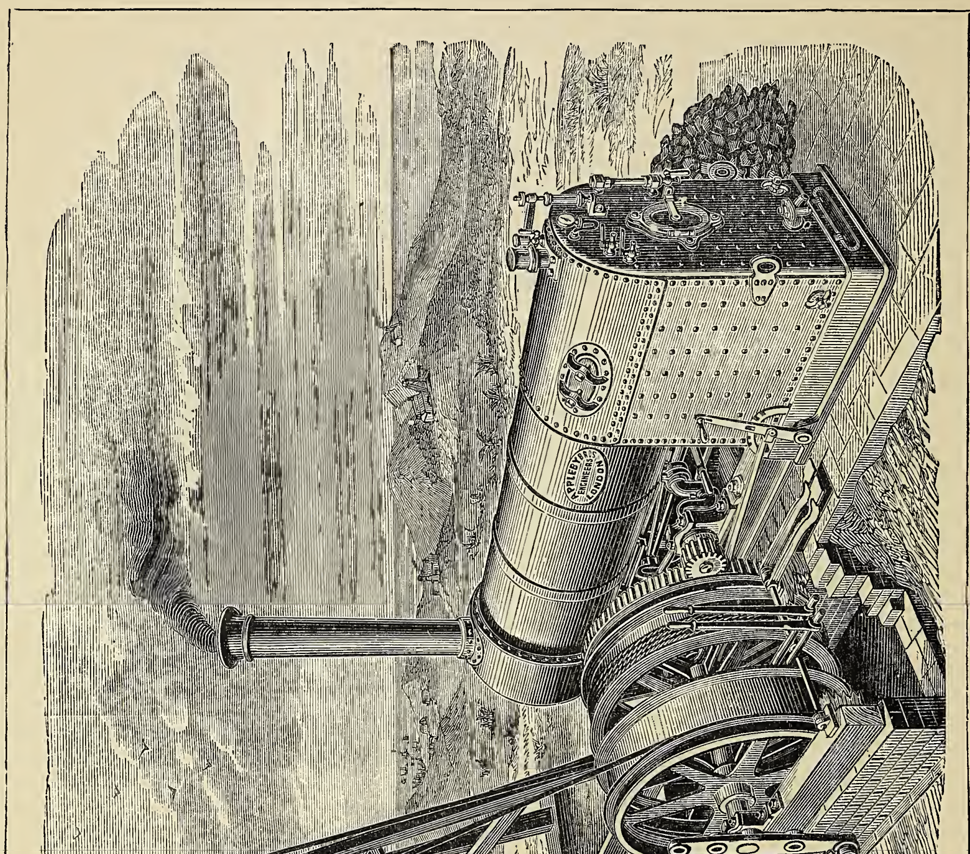


Fig. 64.—Winding Machinery for Mines.

have a *fact* in relation to miners, rather than a string of speculative opinions. Such men literally carry their lives in their hands. They are at every moment liable to fatal results, from the slightest error on their own or the part of others; and if at any time we find them reckless, we need not look low in society to find their counterpart, under far less justifiable circumstances.

In the eloquent words of the eminent geologist we have already quoted (Ansted), we, with him, appeal to society at large for consideration of these men. "For whom do these men suffer? Their widows and orphans, their mothers, their sisters and their friends, have a right to call upon every one of us, who benefit by their labours, but take no thought of their dangers and sufferings. They labour for our benefit. We induce them to run these risks, and are bound to weigh carefully the great social relations which impose it as a duty upon us to improve their condition. Each event of this kind (an explosion) concerns us all; and we are all, without exception, responsible in degree; for if a sufficient interest were felt and expressed in this matter, it would not be allowed to go on as it does, from accident to accident. That the subject is obscure and difficult is not a sufficient reason that it should be neglected; and because the sufferers are patient, the place of the accident far removed, and the objects of it beyond the sphere of our immediate exertions—because few of us have visited a coal mine, and know nothing of the danger personally—we are not, therefore, at liberty to let the matter take its own course without an attempt to do good. Some pity should be felt, and some sympathy also expressed, for those whose lives are spent, and whose deaths may be caused, in providing us with the means of comfort and enjoyment. Let us think seriously how much we owe to them—the comfort of the fireside, that essential requisite to home enjoyment—the luxuries that surround us—the facilities for travelling—the use of, and interest in, all machinery and manufactures (all these we owe to the coal miner);—and then think how little we do for him in return. He must daily descend some hundred yards into the bowels of the earth, traversing many miles of low, subterraneous passages—performing his task in the most inconvenient posture, in an atmosphere always impaired, and choked with dust, if not actually dangerous; lighted by a small candle, or by the yet fainter glimmer penetrating the meshes of a wire gauze; and then, from time to time, exposed to the chance of these accidents. He troubles not our repose; the tale of his distress hardly reaches our ears; he is poor; he is far away; he dies!—but he is our fellow creature and our countryman. Each one of us is related to him by many bonds; and it is our duty to see that every practical method is adopted to improve his condition. And if the danger around him must still remain, in spite of all our exertions; if the terrible accidents from explosions must sometimes occur, still we have a duty to perform; for we are bound to use every means to diminish their frequency and extent, and to take away, if possible, from them their frightful results. This duty is one not only affecting the legislature, but every individual amongst us; for all may, in some way, either directly or indirectly, have influence with those upon whom ultimately the responsibility of so great an act of public justice must fall."

We are sure that all our readers will heartily approve, and cordially assent, to the noble appeal which Professor Ansted thus makes in relation to the miner. We have prefaced it with a few facts which we are personally acquainted with, by way of introduction; and now, to supplement it, we enter into an inquiry respecting the real dangers of coal-mining, and the means that have been adopted (we regret, useless, as seen from many recent events) to prevent or remedy them.

Ventilation of Coal-mines.—Of course, the presence of so many persons, horses, lights, &c., in a coal mine, must soon vitiate the air, and render it unfit for respiration and combustion. It is, therefore, absolutely necessary that a supply of fresh air should be afforded constantly; and this is effected by having two or more shafts in large mines; or, in a small one, the single shaft is divided into two as already explained. Taking the case of more than one shaft being provided, one or two are used to supply the air to the mine, and called the *downcast;* whilst the third withdraws the vitiated air, and is called the *upcast.* The draught is created by causing a current to rise in the upcast from the mine by a large furnace, kept continually burning. In fact, the principle and practice are precisely the same as we notice in the fireplaces of our houses. Supposing, for example, that every access of air into a room was prevented except by two chimneys proceeding from it. If a fire be lit in the grate of one of them, it would instantly cause an updraught. But no draught could continue unless some means of a supply of air were afforded. The chimney without the fire at its base would serve this purpose, the cold air descending into the room rushing through the fire, and again reaching the open air by the chimney over the fire. If our unpractical readers transfer this illustration to the coal mine, they will find represented in the room—the downcast shaft in the chimney without a fire, and the upcast, that with a fire at the base. Ventilation is thus mostly, or with barely an exception, carried on in coal mines.

But the parallel between our illustration of the ventilation of the room and the coal mine is but partial; for the mine is not one large open space like the room, but is formed of narrow passages, intersecting each other in all directions. Now, not only does the narrow character of these galleries or passages impede the air, but their intersections would stop its progress, except in a direct line between the downcast and upcast shafts. Hence a variety of contrivances have been introduced to direct the fresh air into every part of the mine, so that its entire ventilation may be effected as completely as possible. Formerly, the air was al-

lowed to travel continuously through the whole pit; consequently its progress was extremely slow; for the force of the downward draught was gradually diminished by the mere friction of the air against the sides, bottom, and roof of the mine; and the result of this was, that the ventilation was exceedingly imperfect, and even comparatively safe mines became unnecessarily dangerous. "It was found, however, at last, that if a current of air were allowed to select between two districts, both of which communicated with the upcast, it did not take the shortest way, and leave the other untraversed, but divided itself—a certain part going off through one set of galleries, and another also through the other set. When it was tried what the quantity of air thus passed in each case might be, it appeared that the sum of the two quantities was very much greater than what had passed through before. In this way this important principle was established—that *the quantity of air brought down into a mine might be increased by increasing the number of distinct currents to the air-shaft.*" This result was of the most valuable nature; and now, by splitting the air in its current from the downcast to the upcast shaft, its rapidity of motion is greatly increased; and where formerly the single current would have had to travel sixty or seventy miles, the direct course in the same mine, of all the currents, has been diminished to a twelfth part of that distance.

In the ventilation of a room, house, hall, or church, we have always a great natural aid in the fact that, as hot air is lighter than cold, it rises to the top of either of the spaces we have referred to. Thus, in an ordinary room, a draught of cold air enters at the lower part, and the hot air leaves it at the top; so that an opening at the top and bottom of a building, will at all times ensure a measure of ventilation, which is still further improved or exalted by a fire, gas, or candles burning, or other source of heat—even of the bodies of those who may sit in such an apartment. But this aid is entirely absent in the coal mine—the sides, top, and bottom of which are nearly all of the same temperature, and their height and width being too insignificant to have any influence in creating a draught. Thus, if a mine with two shafts—say one at each extremity—be left unworked for some time, and no artificial means, as of the furnace, be employed to create a draught, its lower portion becomes gradually filled with any gas heavier than the atmosphere; especially with carbonic acid gas, of which we shall have to speak more fully in connection with *choke-damp*, and which is not only unfit to breathe, but is positively destructive of animal life—even instantly extinguishing a candle immersed in it; hence the numerous fatal accidents that have occurred in breweries and distilleries, where large vats affording this gas are employed. By means that we need not here describe, these frequently have the lower part occupied with the poisonous gas; and if a workman descend therein with the vat in that condition, the chances are that he will endanger his life. For similar reasons, therefore, deep wells are unsafe to descend into, without being first tested as to the quality of air they contain.

From all these facts and considerations, it will be perceived that the ventilation of a coal mine must necessarily be *entirely artificial.* It is impossible, therefore, to speak too highly of the importance of the subject; more especially when we state, that all colliery accidents have resulted, more or less, from deficient ventilation; for, no matter how foul a mine may be, if sufficient means could be adopted to constantly renew the air, and provide an adequately rapid and abundant current, a dangerous explosion would be rendered all but impossible; and if not, its fatal consequences would be greatly diminished.

It would be impossible to convey to our readers unacquainted with the arrangement of a coal mine, an idea of the various methods employed to direct the air in any special course. They, however, may gain some general view by considering the different plans adopted in the supply of water in our large towns. By means of valves, we all know that the water can be turned on or off from the main—sent down one street, and shut off from another. Now, precisely such a principle is adopted in the coal mine. The air, like water, is a fluid; and, by means of solid stone walls, called "stoppings," its passage may be stopped or directed. But the roadway of a mine cannot be thus completely impeded; hence temporary means of stopping the passage of the air are adopted. Doors are fixed in the mine, that are kept shut until a truck is required to be passed through them; after which they are instantly closed by a boy, whose business is solely to attend to that duty. There are main doors, shell doors, &c.; tunnels arched over a passage, and other such contrivances; all of which have one object—that of promoting, in one direction, a regular current of air from the downcast, or supply shaft, to the upcast.

If, however, all these contrivances be ever so complete in detail and principle, the ventilation of a mine may be temporarily impeded, or even quite stopped in certain portions of it, if the lad or man left in charge of the main or other doors neglected his duty. If, for example, a door be left open, of course its object, of diverting or stopping the passage of air, becomes at an end, and two or more currents may meet, that will entirely destroy their individual or collective passage. Thus the lives of hundreds of men may be at once jeopardised by the neglect of one; for if, at such a moment, an outburst of gas take place from the coal, no possible chance of escape could exist; for the ventilation being stopped, the gas might, by accident, ignite, and fatal results would accrue. To this proximate cause many serious explosions may be traced—and that the mere opening or shutting of a door!

Having thus explained the principles and details involved in the ventilation of a coal mine, we next turn to inquire into the causes that produce explosions; and the remedies, other than ventilation, which are adopted, or have been tried, with varying success.

Coal is composed of *carbon*—represented familiarly by the diamond, which is pure crystalised carbon, less purely in charcoal, and still less so in blacklead, which, although so called, does not contain a particle of lead in its composition—of *hydrogen*, a highly inflammable gas, forming one-ninth part of water by weight, and from which it may be withdrawn by putting some iron or zinc nails into water, to which has been added one-eighth part of sulphuric acid—and of *oxygen*, that forms one-fifth part of the air we breathe, eight-ninths of the water we drink, and, in fact, constitutes nearly one-half of the crust of the earth, and its living occupants, whether plant or animal. Besides this, coal contains, to a much smaller extent, nitrogen, arsenic, sulphur, iron, &c. ; of which, for the present, we shall take no notice, because they are apart from our purpose.

If a piece of coal be powdered coarsely, and put into a glass retort, or the bowl of a common tobacco-pipe, the open part being stopped with clay, and either of these, so charged with coal, be heated gradually to a red heat, the first product given off will be *water*, produced by the union of part of the hydrogen with part of the oxygen of the coal.

But, as the temperature approaches to a red heat, other products are given off, all of which we shall let pass unheeded, except the gas. This will issue from the stem of the retort, or pipe; and if a lighted match be brought in contact with it, ignition will ensue. This gas, in fact, is the same as our ordinary coal gas used for illuminating purposes, but very much more impure.

Now, this coal gas results from a union of part of the hydrogen of the coal with its carbon ; and hence is termed by chemists a *hydrocarbon*—a term evidently expressing its chemical constitution. Into this matter, however, we need not here enter, because it would lead us far away from the practical part of our subject.

Although not strictly in accordance with our knowledge of chemistry, we may state that the gas afforded after the manner just indicated, may, for our purpose, be considered as identical with that found in coal mines, and that is naturally produced from coal in that condition.

Now we well know that coal gas, lit at the top of a burner, produces no noise and no explosion. If, however, we fill a strong soda-water bottle, so that it shall contain about one part of coal gas to about ten of air, and a light be applied to the mixture, an explosion instantly ensues. The hydrogen of the coal gas unites with the oxygen of the atmosphere, and then water is formed. From the same cause—the presence of air, and gas escaped from a pipe in an apartment—the terrific gas explosions in our houses occasionally occur.

This gas, given off from coal, is, as we have just stated, identical nearly with our artificial gas; and, like it, burns quite quietly when ignited at the fissure from which it issues in the coal mine. If, however, it be allowed to mix with air, and is ignited, precisely the same result occurs as that we have mentioned with coal gas and air in the soda-water bottle or the room—a violent explosion ensues. It is the mixture of the gas—called *fire-damp* by the miners—with air, and its ignition, that is the immediate cause of our colliery explosions.

Some idea of the force of such gas explosions, which will blow down brick and stone walls, doors, &c., and drive everything before the blast, may be gathered from two instances. The following, we witnessed. By the carelessness of a servant, a gas-tap had been left partly open for about an hour, in a parlour measuring nearly twelve feet square, and eight feet high. A light was taken into the room, and an explosion ensued that destroyed all the furniture, blew off the door, and did much other damage in the house ; but, besides this, every square of glass was broken in five houses facing this one, but sixty feet off. The second instance is related by the late Dr. Letheby. He gave a report of a fearful disaster of this description which occurred some years ago in Albany Street (north-west of London). The gas accumulated in the shop for a very short time only ; in fact, it had been escaping no longer than an hour and twenty minutes, from a crack in the meter. The area of the room was about 1,620 cubic feet ; but when the gaseous mixture ignited, it blew out the entire front of the premises, carrying two persons through a window into a back-yard, and forcing another, by the violence of the shock, on to the pavement on the opposite side of the street, (a distance of fifty feet), where she was picked up dead. For more than a quarter of a mile, on each side of the house, the effects of the explosion were severely felt, and the glass in most of the windows was shattered ; but the most extraordinary evidence of its enormous power was exhibited in the condition of the premises which immediately faced the house that was destroyed. In one of them the iron railings around the area were snapped asunder ; and, in another, a part of the roof and back-windows was carried to a distance of from 200 to 300 yards; besides which the pavement was torn up for a considerable length. According to the official report, which was made to the insurance offices, it appears that 103 houses were injured by the explosion.

A careful perusal of these two instances of gas explosion will give some idea of the effects of a colliery explosion. But in both the cases we have cited, the roadway, or street, was not less than fifty feet wide; and, of course, open to the clouds upwards. If, therefore, we only assume that the trifling amount of gas mixed with air is similarly exploded in a coal mine, and in place of the unbounded space of open air, we bear in mind the narrow-channels of the mine, often less than six feet high, and of proportionally narrow breadth, our imagination may readily conceive the dreadfully destructive effect that must ensue.

But the *fire-damp* is not the only danger of the miner. Its after-effects are often more fatal. When gas is burned, either quietly in our houses, or during an explosion, two compounds are produced—one being water, as already explained, and the other is the carbonic

acid, to which we have alluded at p. 14, *ante*, as found in deep wells, unused mines, &c. This gas, familiarly known as causing the froth in beer, champagne, and other sparkling liquids, constitutes the *choke-damp* of the miner. We have previously pointed out that it is not only incapable of supporting either life or combustion, but that it is positively poisonous.

Now, the instant an explosion of gas, or fire-damp, in a coal mine ceases, this gas is its result; so that if the miners escape the fire, or violence of the explosion, this deadly product immediately assails them. Terrified with the noise, fire, heat, and dust of the explosion, they take a few hurried respirations, fall down insensible, and, alas! in too many cases, sleep the sleep of death. Practically, indeed, the choke-damp is always more fatal than the explosion; for, generally, but few are directly killed by this. But as its violence destroys all the means of ventilation, the gas it produces cannot escape, and thus is left to do its deadly work without let or hindrance.

It is owing to its presence that great danger exists of descending into a mine to render assistance after an explosion; for those who would heroically lend aid, would, in all probability, fall victims to its influence on gaining the bottom of the shaft. It is very much heavier than atmospheric air, and therefore, for a time, settles, like water, at the bottom of the mine. If the coal catches fire, to a certain extent a benefit may arise, because then an upward draught may thus be created by one or more of the shafts. Hence what apparently would be an increase of the evil, may partly become its cure.

A variety of causes tend to produce explosions in respect to the issue of gas. Occasionally it accumulates in *goafs*, the nature of which we have explained at p. 10, *ante*. Sometimes the pick of the miner will set free pent-up gas; or, at times, old workings are broken into. Another influence is that of alterations of atmospheric pressure, as indicated by the rise and fall of the mercury in the barometer; and to this, we believe, but too little attention has been directed. Most explosions occur during periods of violent barometric fluctuations; and a certain amount of attention, on the part of those who have to inspect a mine, to the indications of the barometer, may tend to add an element of prevention, if not of safety. The fall of an inch in the mercury of the barometer, relieves all surfaces of a pressure equal to half a pound per square inch, or seventy-two pounds per square foot. It is familiarly, again, known to us all that drains smell under such circumstances, because of the gases that cause them being relieved of atmospheric pressure; hence the smell of drains is considered an indication of change of weather. The gas of the coal mine is under precisely the same condition, and therefore equally subject to the same laws, and their results.

But the immediate cause of the explosion, in the first instance, is frequently the flame of the light used by the miner. In some workings, open—that is, unprotected—lights, such as candles and oil-lamps, may be used; the latter being often fixed in the cap of the miner. They, as they emerge from the pit at night, present a peculiar and unique appearance. On one occasion, whilst walking at night with a friend completely unacquainted with mining matters, in a wild part of Lanarkshire, in Scotland, we encountered about fifty miners, who had just emerged from the pit with their lamps so fixed. Their bodies were quite invisible, and their weird-like appearance, or rather that of lamps moving about five feet above the ground, had such an effect on our companion as to produce the most violent effects of fright, from which he did not recover for some time.

It is not every coal-field that is equally dangerous with that of the Newcastle district; and the bituminous kind, which affords most volatile matter, is that most prolific of danger. But still, even the anthracite mines of South Wales, as shown by several accidents, are equally dangerous. After all, with some exceptions, no pit can be called absolutely safe to work in with naked lights. The miner can never tell when he may strike on a portion of the coal that, being broken, shall send forth the fire-damp, the ignition of which may, without a moment's warning, hurry him into eternity. It is therefore impossible that too much care can be taken; and we believe that, in a majority of cases, the owners and superintendents of collieries are free from blame in respect to the causes of explosions, so far as it lies in their power to prevent them. But not only are naked lights a source of danger, but the method of blasting is equally so. Of course, if any gas be escaping near the place at which blasting is being effected, its ignition must be the result; hence the desirability of efficient machinery, which has been recently invented for the purpose of digging out the coal in a mine.

It will be seen, from these remarks, that the suddenness of the evolution of gas is a common source of danger. Not only is there a regular and constant exuding of inflammable gas from the coal, but there is momentarily a danger of its being free to an extent that all ordinary precautions, in respect to safety, would become futile. "In the course of pursuing the working of collieries into the whole coal, the miners frequently cut across fissures, which are in the roof, or in advance, full of inflammable air in a highly compressed state; and these, frequently before they are approached, break away the coal or the stone, when it becomes too weak to resist; and in a very short time, even in a few minutes, from a state of apparent safety, a pit becomes completely charged to the point of explosion, from the immense quantity of gas rushing from the fissures, which are thereby technically called *blowers;* and a precisely similar effect takes place in breaking into old works; and, in both cases, the discharge of gas entirely overpowers the (means of) ventilation." Numerous methods were tried to obviate the dangers arising from the causes that we have described; but it was not till about 1815 that any efficient plans of

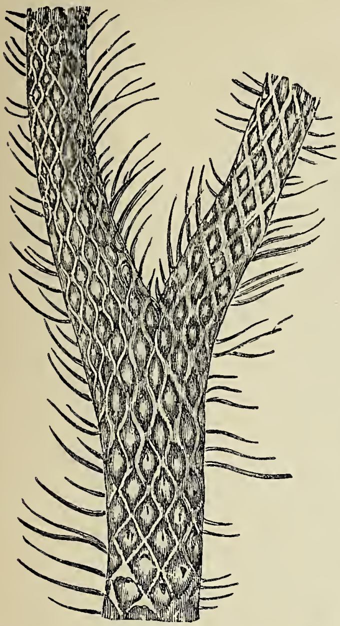


Fig. 65.—Lepidodendron sternbergii—fossil plant in Coal.

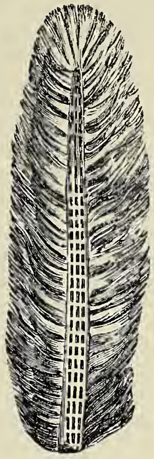


Fig. 66.—Lepidostrobus variabilis—fossil plant in Coal.

Fig. 69.—Odontopteris brardii—fossil plant in coal.

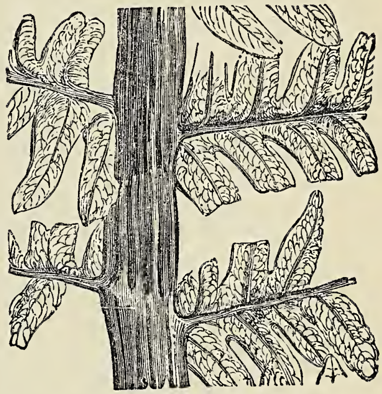


Fig. 70.—Orbicularis—fossil plant in Coal.

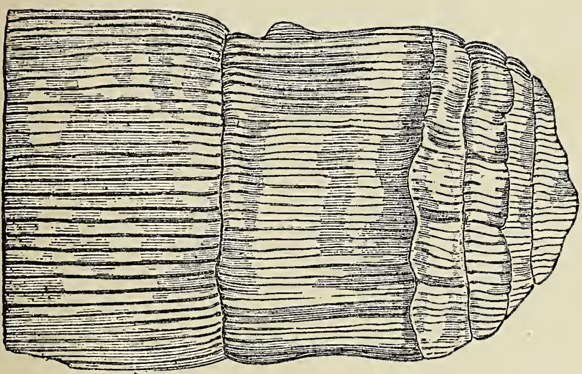


Fig. 67.—Calamites dubius—fossil plant in Coal.

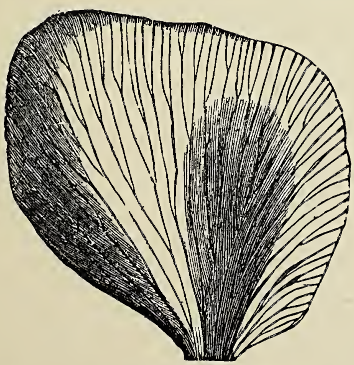


Fig. 68.—Lonchopters bricii—fossil plant in coal.

Fig. 71.—Sphenopteris artemisiæfolia, magnified—fossil plant in Coal.

protecting the light of the miner were arrived at. According to Mr. Barlow, it was in the year 1813 that a society was formed for the purpose of preventing accidents in mines. It was headed by Dr. Gray then rector of Bishop Wearmouth (Durham), afterwards Bishop of Bristol. Sir H. Davy was consulted on the matter; and the result was the invention of a lamp, that, under all its modifications, has borne the name of the "Davy," although very strong pretensions have been advanced of the celebrated George Stephenson having been the first inventor of such an arrangement. He was, about that time, engineer of the Killingworth pit; and from the opinion of his share in the invention, the lamp then used was denominated the *Geordie*. Stephenson's lamp had an external cover of glass that was not used in the Davy lamp.

Whatever claim of priority of invention may be asserted, it is quite certain that to Davy we owe the science, and, to a large extent, the peculiarities of construction, of the so-called safety-lamp.

Those of our readers who are desirous of entering fully into the details of Davy's investigation into the nature of flame, that forms the basis of his invention of the safety-lamp, will find full particulars in the *Philosophical Transactions* of the Royal Society, for the years 1816 and 1817. Sir H. Davy also published, in 1818, a treatise *On the Safety-Lamp for Coal-Miners, with some Researches on Flame*—a work that we have not seen, and which has, doubtless, long been forgotten. But the principles on which Davy proceeded, and succeeded, may be expounded as follows.

A very high temperature is required to maintain incandescence sufficient to produce ordinary luminous flames; and hence if the requisite temperature be not sustained, flame-giving light cannot be maintained. For example, if a copper wire be so twisted that it shall have a ring, at one end, of small diameter, as shown in Fig. 72, and it be placed over a small flame, as that of a taper, the flame will cease to exist above the ring, simply because the latter abstracts so much heat as to reduce it below incandescence. The thickness of the wire determines the conducting power in respect to the diameter. Or, in other words, if the aperture be diminished, the thickness of the wire may also be. If, therefore, a piece of fine wire gauze be substituted for the ring, precisely the same effect results. The metal carries off the heat of the flame; and, therefore, such a piece of gauze being placed on a gas flame will entirely stop ignition at its upper surface, although the unconsumed matter that passes through may easily be ignited by a match on the upper side. The principle, therefore, of such an arrangement, is that of so cooling down the gas burning beneath by the conducting power of the wire, that, on the outer surface, its incandescence becomes impossible, so far as relates to ignition by the flame within the gauze.

Fig. 72.—Principle of the Davy Lamp.

The annexed cut (Fig. 73) illustrates the Davy lamp, constructed on these principles. A is that portion which contains the oil; and B shows a cylinder of wire gauze, that protects the flame from contact with the atmosphere external to the wire cylinder. At the top is a hook, by which the miner, with the aid of a nail, can hang the lamp when he is at work.

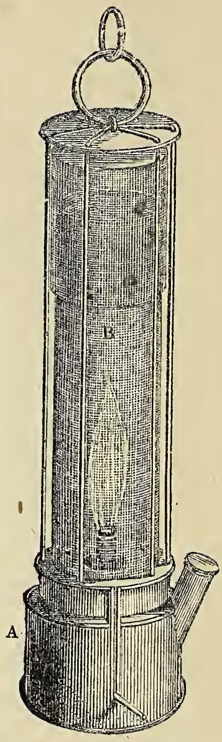


Fig. 73.—The Davy Safety Lamp.

Many modifications (at least, we have seen and experimented with eight or nine, as the Belgian, &c., &c.) have been made of the Davy; still, after the lapse of more than half a century, the same general principle is involved in the construction of all; and the old name of Davy, yet used, asserts the fact. How far such modifications have been improvements, or have effected any better results than the original, may be a matter of opinion. But one point is certain; and this is that although the Davy has been of inestimable advantage, and has doubtless, saved thousands of lives, it is yet a desideratum to produce a lamp that shall not only be safe, but give more available light than any form of the Davy yet constructed can afford. And in this point lies the danger of the Davy. The side is always locked by the lamp-man when he delivers the lamp alight, at the bottom of the pit, to the miner about to proceed to his work. But in very frequent instances these men have supplied themselves surreptitiously with keys that will open the protecting cylinder; and these they use to obtain a light for their pipes, or to give a better light to work by. For, as the man is paid piece-work—that is, by the amount of coal he delivers at the bank-top, or mouth of the pit—it is a matter of importance to him to hasten his labour as much as possible. In some respects the Belgian lamp has an advantage; for, as a portion of the gauze that obstructs the passage of the light is replaced by glass, of course the miner has more light to work with. It has been actually known that the men will draw the flame through the sides of a Davy, for the purpose of lighting their pipes, a circumstance easily effected, because a blast of air will entirely, by driving the flame through the gauze, obviate its efficiency.

Professor Ansted sums up the causes of want

Sir Humphrey Davy

of safety in the Davy, apart from carelessness, wilfulness, or negligence, under the following heads, and with the observations here given :—1. Exposure to a jet of gas, whether explosive or pure, after the carbonic acid gas at the bottom of the lamp has been removed. This is readily illustrated by forcing the gas issuing from a common street-pipe through the sides of the lamp, in a burning state. 2. Exposure to a mixture of sulphuretted hydrogen, of pure hydrogen, or of olefiant gas, with the light carburetted hydrogen, as it is commonly found in mines. It is said by some chemists that these gases are occasionally present in coal mines; but we have the authority of Henry, Thomson, and Davy, and more recently, of Professor Graham and Dr. Lyon Playfair, for stating that they are not found in the explosive gases of the north of England, or elsewhere, as examined by them. 3. By the burning of small fragments of coal adhering to the gauze. This is rather assumed as possible than distinctly known. It was tried by Davy with street gas; but the result was doubtful. 4. By the falling of fragments of coal, &c., from the roof of the mine, and the consequent breaking of the lamp. These are all cases in which the Davy lamp may, it is said, be the means of causing an accident by explosion; and some of them would be avoided by the use of the improved lamps, of various kinds. On the other hand, it may be said that the experiments made by mixture of street gas with common air (by which the value of some of these lamps has been tested), are not altogether satisfactory, since the gas produced from distillation of coal is more explosive than common gas in mines, and is so at lower temperatures. . . . . With regard to the relative value of the different safety-lamps that have been introduced, the shielded Davy may be said still to keep its place. In its great simplicity, its proportions, and portability, and in its being the best known to the miner, this lamp must be considered to possess many advantages over any other; and it may be doubted whether a greater degree of safety is really and effectually produced by other contrivances. It has now been in use for sixty years: and in almost every case where danger is known (and how frequent these cases are, those only are aware who have visited the mines themselves), it has been trusted implicitly, even to folly, by the superior officers of the mines, in thousands and tens of thousands of doubtful cases, and when it was well known that explosive mixtures existed. In by far the greater number of the pits in the Newcastle coal-fields, the viewer proceeds, at least once every day, with this instrument, through the districts actually worked, before they are visited by the men; and every week, or fortnight, through the rest of the mine where the gas is most likely to accumulate. And if occasionally—and it is a very rare case—there has been an explosion when no other cause could be fairly assigned than the Davy lamp, we ought not to leave out of consideration the innumerable instances in which it has proved itself to be, when properly used, a sufficient safeguard.

Generally speaking, it can scarcely be doubted that accidents occur through the carelessness of the men. As an instance of this, we may relate, that Faraday was, some years ago, deputed by the government to make some inquiries in reference to the cause of colliery explosions. Whilst in the mine, sitting on a tub, and holding a naked candle in his hand, he questioned one of the men as to where the gunpowder was kept. The miner informed Faraday that he was himself sitting on a tub full of it. Not long ago, a man, working in one of the Durham collieries, in a drunken freak put a poker into the fire, went to his upper room, and fetched down a keg of powder; sent for a female neighbour, who came with a child; and, as soon as she got into the house, he deliberately thrust the red-hot poker into the powder—blew up his house, killing the child, and seriously injuring himself and the female. It is, unfortunately, too often the case, that constant contact with danger hardens men to such a degree as to make them perfectly indifferent to consequences. The following we can vouch for, from personal knowledge:—A man, formerly employed in a business of considerable risk, applied to a firm to drive the engine. The boiler was known to be rather "shaky;" or, in other words, not quite safe. On the men entering the factory, and passing the stoke-hole, on a Monday morning, he asked them if any wished to go to a place which we shall not name; if so, to follow him. He sat down on the safety-valve, which was then blowing off at a much higher pressure of steam than was safe; and there quietly waited until the boiler actually blew up, but, fortunately, without injuring any but himself; he paying the penalty of his folly by breaking one leg. As a last instance, we were informed by a gentleman owning large quarries, that the men would not explode the mine or "shot" by electricity, because no possible danger to them could arise from the plan; they arguing that, in the absence of danger, their wages would be lowered!

Fully convinced, therefore, that the majority of the colliery accidents are avoidable by care, the proper use of the Davy, and thorough ventilation, we shall refrain from drawing attention to the numerous reports that have been issued by government inspectors, commissioners, and others who have, in nearly all cases, arrived at the same conclusions as those already expressed. It may be interesting if we give a short account of the dreadful explosion that took place at the Oaks colliery, near Barnsley, that we have already more than once referred to, and in which one of the greatest sacrifices that has ever been recorded in mine explosions, of human life, in one event, occurred. At the Lundhill explosion, in the same neighbourhood, in 1857, about 190 lives were lost; and this number was exceeded at the Hartley colliery, by a different cause, in January, 1862, when 209 live were lost, through the breaking of the engine beam, that destroyed the shaft, and cut off all means of escape for the miners—they being starved to death. About seventy-five persons were destroyed at the Oaks colliery in 1846; but the explosion which we

have now to notice, and that happened in December, 1866, sacrificed above 350 lives.

The colliery is situated about a mile and a-half from Barnsley; and its extent is one of the largest of the South Yorkshire coal-fields. The usual number of hands employed was about 450. Some idea of the size of the colliery may be gained from the fact, that the extremities of the workings are distant three miles. The principal part was that known as the "dip," down which ran a broad roadway, termed the engine-plane, and extending nearly a mile. From this the workings were continued by levels, in the usual manner. Three shafts were provided to the mine, each above 285 yards deep—two of them being downcast, and near to each other; and the upcast was several hundred yards away. The air that passed by the downcast shafts circulated through the workings, and escaped by the upcast, the draught of which was accelerated by a large furnace kept constantly alight, so as to keep up the ventilation as efficiently as possible, after the manner we have explained. No relays of men were employed, as is usual in collieries; but they worked in a body for eight hours a day only—a most humane and excellent system; for, in many parts of the north, we have seen miners, fresh out of the pit at night, turn into a bed not yet cooled, after the man who had just left it, to take the place of his fellow-worker. About ten minutes past one in the afternoon, a slight tremulous motion was felt at the mouth of the pit, followed by a heavy explosion that was heard a mile off; and instantly dense volumes of smoke and dust were driven into the air from each shaft, which, of course, conveyed too certain information of the dreadful occurrence that had taken place below. As soon as an examination could be made, it was found that one of the downcast shafts had been rendered completely useless; and the rope of the other was injured, so that it could not be employed. Here we see the value of a second shaft, already urged as indispensable for the safety of the miners, at p. 8, *ante*.

A descent was made down the shaft, and some bodies were recovered. The pit did not, from cursory examination, appear to be on fire; but it abounded with choke-damp so that many of the exploring party had to return. We need not describe the scenes that occurred, as one dead body after another was recovered, and raised to the mouth of the pit. However, on the next morning, airways were temporarily fitted up, so as to produce some ventilation; and further search, by a party of volunteers, was made: but a second and terrific explosion took place, when the body of men, about thirty in number, who had thus heroically risked their lives, sacrificed them in the cause of humanity. Scarcely had the effects of the explosion cleared away, when a third followed, which was not so severe as the two preceding, but sufficient to stop all further search. As the day wore on, it was evident that the pit had caught fire, for the current of air had been turned, and a cloud of smoke was rising from the downcast shaft; and eventually the upcast shaft became downcast, showing that the system of air current had been completely changed from that previously subsisting, when proper ventilation, before the explosion, had been in progress. Strange to say, on the Friday, as the explosion took place on Wednesday, December 12th, the pit signal-bell was heard to ring at the head of the shaft, the smoke from which had subsided; and, after some delay, the only one who returned from the pit alive was brought safely to the surface by two volunteers, who descended in a cage. This man had been at first overcome by choke damp; but recovering, he essayed to reach the bottom of the shaft, stumbling over scores of corpses of his fellow-workmen. It was evident that the pit was on fire; and it was determined, that as no possible benefit could arise from further search, none should be attempted. Eventually the mine was stopped up, to prevent any access of air, and so to put out the fire.

Such is a brief account of one of the most terrific explosions known in the annals of mining, and which, strange to say, was followed by another, in the neighbourhood of Newcastle-under-Lyne, in Staffordshire, on the day after the first explosion, and within an hour of the second explosion, in the Oaks colliery. Of course the many miles of distance between the two rendered any connection in the cause of each impossible. The colliery belonged to the North Staffordshire Coal Company; and the pit in which the explosion took place is about 360 yards deep—the extent of the mine already worked being about 600 yards north and south, with a seven-feet thick seam. It was always very dangerous, and full of gas; hence great care was observed in the workings, and the men generally were provided with Davys. In this case nearly 200 lives were lost.

The extent of the calamity made it impossible, in either of these instances, to discover the actual cause of the explosion. It was stated, in respect to the last-named accident, that a blacksmith was found with a naked lamp by his side; and, therefore, to his neglect the explosion was ascribed by some. But, in both cases, conjecture alone supplied any probable reason; and the truth, of course, will never be arrived at.

Every year presents its sad record of coal min-mining disasters caused by explosion. The year 1880 was remarkable for these occurrences, both at home and abroad. Five of these calamities occurred in England and Wales, at the Dynas, Abercarne, Risca, Seaham, and Pen-y-graig collieries, by which at least 700 persons lost their lives.

In regard to necessary precautions, we can simply repeat what has been before stated—that a thorough system of ventilation is, after all, the best safeguard in a coal mine. It is true that frequently an outburst of gas must take place in the best-regulated mine; but any pit specially subject to such sudden outbreaks, tells its own tale long before any accident need occur. If a person determine to enter on the manufacture of gunpowder, he knows perfectly well that his business must be carried on under certain conditions; that whilst a vast amount of danger

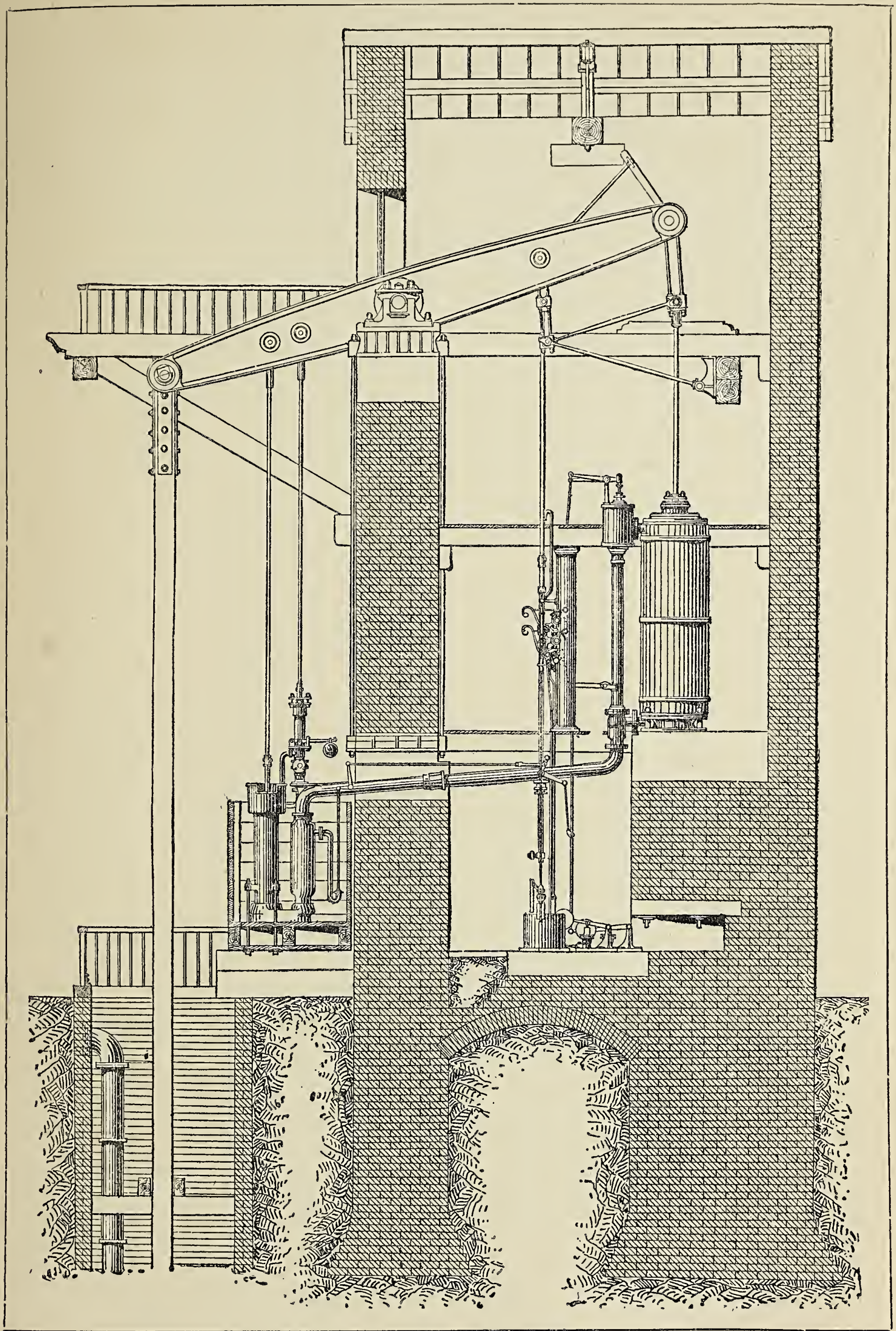


Fig. 74.—Beam Mine-pumping Engine.

may be incurred, yet there is a possibility of avoiding its evils. Now, no one can imagine any possible case more dangerous than that involved in such a manufacture. Yet how few fatal accidents occur, compared to those we witness in coal mines. There is no doubt but that the system of coal-mining, as a rule, is radically wrong. At one time, accidents in cotton and other factories were of frequent occurrence from unprotected shafting: again, steam-boiler explosions were exceedingly frequent. But both of these have been materially lessened by precautions of the simplest character, dependent partly on the applications of science; but with all deference to our favourite pursuit, we believe that some fortunate results have accrued equally from the use of common sense. It is idle to make the excuse for a coal mine accident, that it arose from the sudden escape of an enormous amount of pent-up gas, when owner, viewer, and miner all knew that they daily saw the risk of such an occurrence. We have known cases of a fatal character resulting in mining and tunnelling, that could have been as certainly expected as that the clock should point to one an hour after it struck twelve—instances (and we now speak of iron-mining) in which two or three props of wood would have saved a life. The wood, however, was not in stock; and the man did not care to waste his time—paid by piece-work—to seek for it, and so he entered the next world personally a suicide; and his master cannot be reckoned less in moral crime than a murderer.

It is generally found that sudden fluctuations in the height of a barometer are followed in fiery mines by explosions. The reason of this is self-evident. So long as the atmospheric pressure is high, the pent-up gas is prevented from escaping. But a lower atmospheric pressure, of course, removes this safe-guard. So much has this fact been verified by experience, that at some collieries a barometer has been placed expressly to afford such warnings. But they are little heeded, for, as the men are paid by piece-work, they will run all risks to earn money. Many ingenious inventions have been brought out intended as indicators of danger, but we are not aware that any of them have shown such special value as to lead to their adoption.

It must not be considered that we are judging too severely in general in our preceding remarks. We refer to particular cases chiefly; but they are special instances that illustrate a large circle of such occurrences. And thus, having expressed our views, borne out by facts that will, admitted or not, commend themselves to the truthful judgment of both owner and pitman, we leave a subject extremely painful to all, and a blot upon our social, commercial, and, perhaps, our scientific character as a "producing" nation.

There are many other causes of pit misfortunes than those we have named, that may be more justly ranked under the head of "accidental;" such, for instance, as the breaking of the rope by which the corves, cages, or buckets are raised from the bottom of the pit to the bank-top. But this source of accident is avoidable if proper and periodical examination be adopted. Instances have occurred in which there is little doubt that such accidents have been caused intentionally, through spite or malice, but we must state that they are exceedingly rare in coal-mining districts.

But, frequently, great danger exists owing to the irruption of water into a mine, either from disused workings, or from defective tubbing of the shaft (see *ante*, p. 8.) About sixty years ago, seventy-five persons were drowned in the Heaton Main Colliery, owing to the in-burst of water from some old and unknown mines adjacent thereto. Professor Ansted relates a singular occurrence that took place in Scotland in 1833, when a river, and, indeed, also the sea, entered a mine from the surface of the earth, through some previously unknown channel or crevice; yet in this case no lives were lost. But what we may class as miscellaneous accidents, are rarely fatal to any great extent—the circle of their influence, except in the case of water irruption, being very narrow.

Numerous accidents have occurred in mines, and on board ships carrying coal, from a very singular cause. Most of our readers will have noticed yellow shining masses in some kinds of coal. These consist of a sulphide of iron; that is, the metal in combination with sulphur. When this sulphide becomes exposed to the action of atmospheric air and moisture, it speedily undergoes chemical changes. The sulphur combines with an additional quantity of oxygen, and becomes sulphuric acid, uniting with the iron to form the sulphate of that metal, familiarly known in commerce as copperas, and largely used in dyeing and other industrial processes. But attendant on these chemical changes is the great production of heat; and so high does this, at times, rise, that the coal catches fire. Thus, if a vessel be loaded with damp coal of the kind we have described, and goes on a long voyage, there is considerable chance of the ignition of the coal. In fact, from this cause some kinds are utterly unfit for shipment, as positively dangerous. Numerous accidents have occurred on board ships from rich bituminous coal giving off gas, which, becoming ignited, has blown the vessel to pieces, and caused fatal results.

We have incidentally noticed, at a previous page, that machinery has been invented for the purpose of relieving the miner from the most laborious part of his work—namely, that of "picking" the coal, as in forming the "bord" and "judd," described at p. 10, *ante*. It would be scarcely possible, even with the aid of engravings, to give an accurate idea of the construction of such machines, which are worked either by compressed air, or water-power, as the mechanical details are somewhat elaborate. One of the first inventions of this kind is that of Mr. Jones, of the Blaina Works, near Newport, in Monmouthshire. That part of the machine which effects the removal of the coal, is in no important particular different from the pick of the miner; but the mechanical arrangement, by which an action is given to the pick and machine, similar to that of the motion of

the man's body, as he drives in and withdraws the pick, is very ingenious; and is thus described in the *Mechanics' Magazine* (January 4th, 1867):—

"In the coal-cutting machines invented about two years ago, by Mr. J. G. Jones, it is found necessary, at each stroke of the pick, to give to the machine a backward and forward motion. This has heretofore been effected by the workman attending the machine, by the aid of a hand-wheel. Some attempts have been previously made to render the machine self-acting; but without success. According, however, to an invention recently patented by Mr. Jones, he renders the machine self-acting by applying a small working cylinder, combined with the large working cylinder (analogous to that of an ordinary steam-engine), which gives motion to the pick. The two ends of the small cylinder are connected by pipes, or passages, to the two ends of the large working cylinder, so that the fluid employed (usually compressed air) is supplied into the small cylinder at the same time that it is supplied into the large cylinder, to work the pick to and fro. The piston within the small cylinder is made in two parts, to adjust the length. On each side of the piston there is a projection, and corresponding recess in each of the end-covers of the small cylinder, in which a ring of soft material, or packing, is introduced. There are two piston-rods to the piston of the small cylinder; and they respectively pass through two stuffing-boxes, made in the end-covers of the small cylinder. The outer ends of the two piston-rods are connected to double pauls, or grip-levers, which are carried by rings fitted to the bosses, or centres, of the wheels of the carriage of the machine; and by such means, the piston of the small cylinder, in its to-and-fro motion, by the aid of the double pauls, or grip-levers, alternately gives a slight backward motion, and then a forward one. The backward motion takes place near the end of the stroke of the small piston, and when the pick is in the work. The piston of the small cylinder, and the parts worked thereby, are arranged to admit of adjustment."

From the preceding description, it will be perceived that all the mechanical motions of the man are imitated by the machine. We are almost inclined to fear, that however ingenious such an arrangement may be, and also highly effective under certain circumstances, the general adoption of such an invention must be far distant, and, in any case, of only partial application. In the first place, the varying depth of our coal seams would require special modification or adaptation of such a machine to many circumstances. The "fracture" of coal—to use a mineralogical phrase—is exceedingly uncertain; and the regularity of the machine would rather be disadvantageous, in many cases, than otherwise; for the pitman can adapt his strength and direction of a blow in a manner that might suit any particular class of coal, while the action of the machine being invariable, could not be so modified. We are not aware that any of the inventions that have since been brought out for similar purposes have had more than a very small application, and the collier with his pick-axe still stands master of his situation.

In respect to the vegetable origin of coal, to which allusion has already been made at p. 4, *ante*, a few additional remarks, with illustrations may be made. The latter (see Figs. 65 to 71, p. 17) represent either actual plants, interspersed with and among the coal, or *impressions* of plants, more or less distinct and developed. These impressions occur generally in the "shale" of the coal-measures; that is, in the layers of hardened mud which separate the seams of coal; some occur in the coal-seams themselves, but these are not so numerous or well defined as those met with in the shale. Some of these vestiges of a period so far distant as to be beyond the reach of human records are described as being exceedingly beautiful. Thus, Dr. Buckland, in speaking of the coal-mines of Bohemia, says, "The finest example I have ever witnessed is that of the coal-mines of Bohemia. The most elaborate imitations of living foliage upon the painted ceilings of Italian palaces bear no comparison with the beauteous profusion of extinct vegetable form with which the galleries of these instructive coal-mines are overhung. The roof is covered as with a canopy of gorgeous tapestry, enriched with festoons of most graceful foliage, flung in wild, irregular profusion over every portion of its surface. The effect is heightened by the contrast of coal-black colour of these vegetables with the light groundwork of the rock to which they are attached. The spectator feels himself transported, as if by enchantment, into the forests of another world; he beholds trees, of forms and characters now unknown upon the surface of the earth, presented to his senses almost in the beauty and vigour of their primeval life; their scaly stems and bending branches, with their delicate apparatus of foliage, are all spread forth before him, little impaired by the lapse of countless ages, and bearing faithful records of extinct systems of vegetation, which began and terminated in times of which these relics are the infallible historians."

In most cases these impressions are of leaves separated from their branches, or of trunks more or less in a broken state. Sometimes portions of trees occur in which the vegetable texture is still observable. The leaves are mostly mutilated, and the leaflets of compound leaves severed; flowers are rarely if ever met with; and if fruit occur, it is not in clusters, but separated individually. All the woody portions have the appearance of having been decayed before they produced the impression in the shale, for the bark seems gone, and the convexity of the trunk flattened.

It has been found by naturalists very difficult to fix with any degree of precision the nature of the plants which produce these impressions; but they are divided, for convenience of reference, into three classes: viz., those of which only wood still containing organic structure has been found; those which have an

obvious analogy with recent plants; and those with which no existing analogy has been traced. By means of preparing fossil wood in a particular way, and subjecting it to microscopic examination, it has been found that wood still preserving its texture exists in a mineral state extensively throughout the coal-mines of the north; that in most cases it has a structure analogous to, though not identical with, that of recent coniferous wood; and that, in cases where its structure is not coniferous, it is unlike that of any existing trees. The fruit of some kinds of palms is occasionally found, separated from each other, as if the bunches of the fruit had lain in water till the pulpy parts rotted away and the nuts fell asunder and settled down into the mud. Some of the plant impressions are closely covered either with diamond-shaped spaces disposed in a spiral manner, or by small scale-like leaves, which are supposed to have produced those spaces by falling off.

The most abundant of these impressions are those of ferns, comprising more than half of the entire species. The fruit being seldom found with them, has added to the difficulty of determining their character. Many of the plants consist of short-jointed fragments, with channels furrowed in their sides, and are sometimes partly surrounded by a bituminous coating; they are supposed to have been originally hollow, but to have been subsequently filled up with the substance which fossilized them.

Our illustrations will show the great diversity observable in the plants thus imbedded; whether they be mere impressions of the plants transferred to the substance of what was once a kind of mud, or the plants themselves fossilized into a more or less stony state.

We have already noticed the necessity which exists for keeping coal mines free from water, as far as possible, by pumping. Were this not constantly attended to, in the majority of the coal mines in this country, a large area of our mining districts, especially in the midland district, would be flooded. Numerous forms of pumping engines have been invented for this purpose. The first steam-engine introduced by Watt for pumping large quantities of water from mines, or for the supply of towns, are known as Watt's single acting engine; and although engines of this form are not now made, they give excellent results, and many of them are still at work. A good specimen of the single acting engines was erected at the Chelsea Waterworks, by Boulton and Watt, for forcing water to a height of 130 feet. The steam cylinder had a diameter of 48 inches, and the lifting-pump a diameter of $17\frac{1}{2}$ inches, both having an eight feet stroke.

The Cornish Pumping Engine does not very widely differ from Watt's engine. Although this engine has been greatly superseded by various forms of rotative engines, it has not been surpassed in durability—engines of this class, after working for fifty or sixty years, being still in operation and doing good duty.

The beam pumping engine, represented in Fig. 74, p. 21, was constructed by Messrs. Appleby, of London, by order of Sir C. Fox and Sons, for draining the Bateas Mine, in Chili, and has successfully performed its work for several years past. The steam cylinder is 20 inches in internal diameter, is steam-jacketed, and the stroke is seven feet. The covers are also steam jacketed, the upper ones being provided with an extra long piston-rod gland.

This illustration will enable the reader to understand the general method of pumping water from mines. Of course, the details of all the arrangements must be varied according to the special circumstances that may arise in each individual case. Messrs. Appleby have also brought out an open lift pump for use in mines, deep wells, &c.

The pump (Fig. 75) is especially adapted for working at depths of from 50 to 300 feet, where a large supply of water is required as in waterworks, or the sinking of shafts for mines; in tunnels, &c. The working barrel is within ten feet of the surface of the water. An iron windbore is bolted to the valve box, which is cast solid with the barrel in small sizes, but in large sizes a separate casting is bolted to the barrel. The foot and bucket valves are of the ordinary Cornish double beat equilibrium pattern, having faces of patent metal, so constructed that when worn they can be melted out, and a fresh seating cast in and faced up without affecting the main body of the valve. The working barrel is cast-iron, strongly ribbed and accurately bored, and its flanges are faced and turned on the edges. The rising main, which is slightly larger in diameter than the working barrel, is of wrought iron with strong faced flanges; in small sizes, the pipes have welded, and in larger sizes double rivetted longitudinal seams. All bolt-holes in the pipe flanges are accurately drilled to a template, so that the pipes are interchangeable. When the pump is required for sinking, the upper length of the rising main consists of a casting turned to fit a stuffing box, having feet to rest on a girder, which is placed across the well. The head of the pump resting in this way allows that portion of it which is below to sink gradually as the excavation proceeds, until a further depth of from four to five feet has been reached, when an extra depth of rising main is added, and the work proceeds as before. The pump-rods are of wrought iron, with sockets and keys arranged to be easily disconnected and put together again; the rods are made in lengths to match the lengths of rising main. This type of pump is very suitable for employment with Cornish or other beam engines where a long stroke can be obtained. The advantages obtained are, the readiness with which the pump can be put together and repaired; and the working barrel never being more than ten feet from the bottom of the well, its economical working is ensured. The pump does not require the usual stages for fixing, the head-gear resting on the girders at the top, and the windbore on the bottom of the well, or sump. The conditions under which these pumps may be worked are so numerous that it would be difficult to give a list sufficiently comprehensive to cover all cases; and before

the cost of such pumps can be estimated, it is necessary to know the quantity of water to be

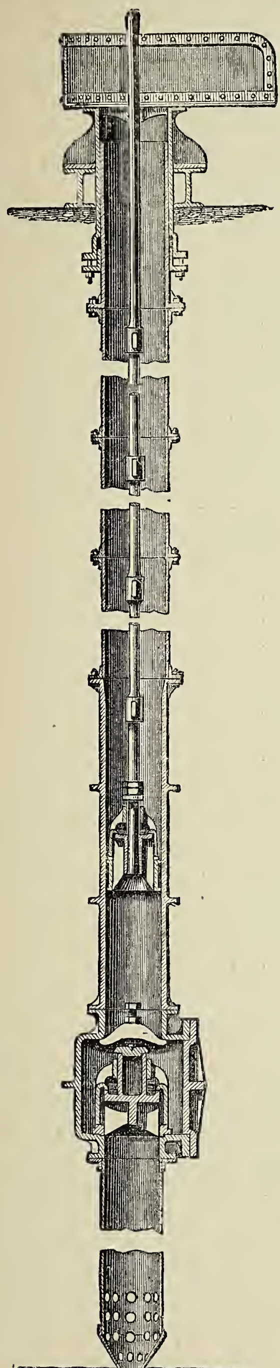


Fig. 75.—Open Lift Pump, for Mines, &c.

lifted in a given time, and the height to which it is to be raised.

Pumps of this kind are extremely durable, seldom getting out of order or needing repairs, and the large number now at work in our deep mines, some of them for many years past, is the best testimony to their efficiency and economy.

The working barrels are made of any diameter, from six inches upwards, and are made longer than the stroke usually required, to avoid the necessity of accurate adjustment, to prevent the bucket striking the bottom.

Allusion has been made, at page 3, *ante*, to various coal fields in foreign parts, we may here briefly refer to:—

The Coal-fields of India.—At the present day the question of coal-supply is one of the most important that engages the attention of the practical man. The enormous traffic that is carried on between our Indian possessions and this country; the equally enormous cost of coal in respect to its shipment from England to each depôt on the routes to India, render it highly desirable that we should attempt to find sources of coal in our Indian possessions that would render the present costly system unnecessary.

Viewed as a coal-producing country, the British territories in India cannot be considered as either largely or widely supplied with this essential source of motive power. Extensive fields do occur, but they are not distributed generally over the districts of the Indian empire, but are almost entirely concentrated in one (a double band of coal-yielding deposits, which, with large interruptions, extends more than half across India, from near Calcutta towards Bombay). This band extends throughout about five degrees of latitude.

A simple mode of representing this graphically, and of showing, at the same time, the area from which supplies of coal may be looked for with any prospect of success, without complicating the question with details of minor importance, is to indicate generally on a map of India, those portions of the country of the geological structure of which we have sufficient knowledge to enable us to assert that there is no probability whatever of any deposits of coal being found within their limits; or where, if coal exists, it must be found at such a depth below the surface that it could not be economised. But to delineate all such coal-bearing strata would greatly trespass on the limits imposed on us in this work. In a report communicated to the Indian Office by the Secretary of State for India, some most interesting facts in reference to Indian coal will be found recited. The report is by Mr. Oldham, the superintendent of the Geological Survey of India, and was made in accordance with the request of the Secretary of State for that country. In a following table we have given analyses of the chief coals found in India. As a rule, the proportion of ash is very high; but in certain cases the volatile hydrocarbons also rank high. The table will doubtless be perused with great interest by many of our readers. It suggests a vast variety of considerations of a practical nature.

The relative amount of ash, which is, of course,

useless matter, materially affects the cost of carriage of Indian coals. If that amount be, on the average, $15\frac{1}{2}$ per cent., it is obvious, that in every ton of coal carried, more than one-sixth of useless material is conveyed; and this becomes a very important element where space or stowage is concerned. The inferiority of Indian coals has prevented them being much used; therefore, in many cases where the fuel is not to a large extent locally attainable, very few sea-going steamers, for example, will burn country coal. To produce a given heat, about one-half more is required of Indian than of good English coal. The ash and clinker amount, roughly speaking, to about 50 per cent. greater than result from the use of English coal; and the staff of firemen and coal-trimmers is, of course, increased in a corresponding ratio. The danger of spontaneous ignition of Indian coals seems to have been greatly exaggerated, according to the experience of competent judges. They do not seem, in this respect, to have an equal risk with English coal. This is not a matter of surprise, considering their average chemical constitution as given in the following table. It is probable, also, that the coal is obtained and shipped in a drier state than English coal, a circumstance which lessens the chance of spontaneous ignition.

In regard to the total production of coals in British India, few reliable data can be obtained. This is not to be wondered at, considering the extent of the country, the peculiarities of the local governments, and a variety of other causes to which we need not more especially refer. A singular fact is, that the three railways alone, which have a termini in Calcutta, consumed more than 200,000 tons of coal annually beyond the total quantity raised in India in 1857, or eleven years previous to the publication of the report just referred to. On the quality of Indian coals, Mr. Oldham remarks as follows :—

"In forming an estimate of the value of coal, and of the proportional quantities which various countries are likely to yield, a very essential consideration is the quality of the coals, as determining their 'duty,' or amount of work done by similar quantities. At first, of course, before coals are worked to a sufficient extent to admit of this 'duty' being tested by long-continued series of practical experiments, the only means of arriving at a satisfactory knowledge is by direct analysis or assay of the mineral. This plan is, however, always subject to error. The portion experimented upon is necessarily small; and it is scarcely possible to obtain, in such small specimens, a thoroughly fair representative of the general quality of a bed. And further, this quality will itself vary, and vary materially, in different parts of the same layer. Still, taking care to select, not picked, but fair average specimens, and combining several of these, it is possible to obtain truly comparable results by assay. In 1862, I had the opportunity of sending to the International Exhibition in London a very fine series of specimens of the principal beds of coal at that time worked in India, and I accompanied these by assays of the same coals. These were chiefly from three fields—Kurhurbali, Ranigunj, and the Rajmahal hills. Many other assays have, at various times, been made in the Geological Survey Office; and I append a list of the majority of these, in which the relative amounts of fixed carbon, of volatile matter, and of ash, are given for eighty different varieties of Indian coals.

Composition of Coal from Indian Coal-fields.

Localities.	Fixed Carbon.	Volatile Matter.	Ash.
KURHURBALI FIELD.			
Mollichooan. . . .	64·9	24·8	10·3
Ditto	68·6	24·8	6·6
Ditto	73·1	22·1	4·8
Passarabhaya . . .	68·5	19·0	12·5
Boreeadeh	66·3	23·0	10·7
Choonjhoonkee. . .	67·2	24·0	8·8
Jutkutti	50·9	15·1	34·0
Ditto	48·2	12·6	39·2
Khandia Hill . . .	57·1	16·4	26·5
RAJMAHAL HILLS.			
Mussinia.	57·60	34·40	8·00
Ditto	48·80	30·40	20·80
Panchbyni	44·2	34·1	21·70
Goomoo	36·00	45·60	18·40
Chilgo	45·50	43·5	11·00
Oormoo	45·00	44·6	10·40
Ditto	45·30	35·5	19·20
Ditto (picked) . .	57·30	41·2	1·50
Bankijora	43·50	42·0	14·50
Teesaphoolie . . .	48·80	37·20	14·00
Ghutkum	43·20	44·40	12·40
Lohundia	45·20	44·80	10·00
Bhora.	25·20	37·20	37·60
Dangaparah. . . .	35·40	45·40	19·20
Ghatchoura	41·60	28·80	29·60
RANIGUNJ FIELD.			
Ranigunj.	50·8	36·0	13·2
Ditto	50·3	36·3	13·4
Searsole	51·1	38·5	10·4
Ditto	57·25	41·00	1·75
Nimcha	47·00	31·50	21·50
Bansra	47·00	40·00	13·00
Mungulpur	43·9	38·4	17.7
Ditto	44·75	37·00	18·25
Babusole.	46·0	35·4	18·6
Madabpur (Harispur).	51·1	35·4	13·5
Parasia	44·00	32·00	24·00
Topossi	49·20	35·40	15·40
Ditto	53·75	31·50	14·75
Chokidanga	56·50	35·00	8·50
Ditto	56·80	34·00	9·20
Dhosul	55·26	34·00	10·74
Jot Janki	48·50	30·50	21·00
Gopinathpur . . .	53·25	35·25	11·50
Bonbahal	48·4	38·7	12·9
Kasta.	61·40	28·00	10·60
Ditto	43·50	32·80	23·70
Jemeri	55·60	84·00	10·40
Futtypur.	63·80	25·00	11·20
Mainanaggur . . .	54·35	35·52	10·13

Composition of Coal, &c.—Continued.

Localities.	Fixed Carbon.	Volatile Matter.	Ash.
Rogonath-Chuck . .	50·50	36·00	13·50
Ditto	46·90	35·00	18·10
Banali	42·60	44·20	13·20
Bhangaband. . . .	40·30	28·40	31·30
Chinakuri	53·20	35·50	11·30
Hatinal	61·00	27·50	11·50
Mahuldabar. . . .	39·20	25·60	35·20
JHERRIA COAL-FIELD.			
Lodona	63·0	26·0	11·0
Ditto	53·8	18	28·2
Ditto	66	21·5	12·5
Ditto	68·4	20·5	11·1
Ditto	65·8	14	20·2
ASSAM.			
(?)	56·94	41·1	1·86
Namber River . . .	30·80	40·40	28·80
(?)	39·8	35·2	25·0
Terap	61·8	36·5	1·7
Namchik	50·4	44·6	5·0
Jeypur	53·0	43·3	3·7
Raipoor	66	31·2	2·8
CENTRAL RIVER. (Pench River.)			
Senda	61	16	23
Burkoi	30·3	26	23·7
Bootaria	49·3	26·5	24·2
Sirgori	61·6	28	10·4
Sonadi	54·4	29·6	16
Burkoi	57·27	24·00	18·73
Mopani (Nerbudda) .	48·54	33·37	18·09
Nepal	50·8	47	2·2
Ditto	34·08	54·02	11·9
Salt Range	46·9	48	5·1
Chittagong	37·15	46·50	16·35
Sandoway	37·3	14	48·7
MADRAS.			
Godavery River . .	23·3	20·5	56·2
Ditto	23·0	17·6	59·4

It may not be altogether out of place here to allude to the great extent of the deposits of another mineral fuel—namely, asphalt found in the Isle of Trinidad—as very possibly bituminous products may eventually be found applicable for purposes for which coal is now used, even, perhaps, for the service of steam-engines. The asphalt of the Ca Brea pitch cake has already been used as a fuel in lieu of coal. It is prepared by depriving it, by boiling, of its moisture and impurities, and mixing sawdust with it to obviate its tendency to run. In addition to the regular bituminous deposits, and the petroleum springs, there are many beds of shale, in the tertiary series, which are rich in asphaltic minerals, and would probably yield an ample reward to distillation. Some of these shales will burn like coal, and could, indeed, be used as such were it not for the very large proportion of residue left after their combustion. One highly probable use of the asphalt would be in the production of gas for illumination; but as there are no gas-works in the island, this has not been practically tried, though suggested many years ago.

So far as this country is concerned, the utilisation of the products of Trinidad, of course, is out of the question. We have already sufficient sources for the production of illuminating oils in the shape of paraffin, &c., besides the enormous importation we make from the United States, &c. Most of the asphalt and analogues, which are largely imported from the continent of Europe, are utilised in this country for the paving of roads; London, especially, of late years having consumed an enormous amount of this material for that purpose, and also for forming pavements in the streets for passengers. It is a curious fact that this asphalt, mixed with sand, &c., seems scarcely to wear away after long traffic on its surface. The Engineer of the Corporation of the City of London has reported, that in the most heavy traffic districts, the result is only the consolidation of the material. It has been objected to as being too slippery for horses, but this is a difficulty that has been got over, by keeping the surface clean by constant sweeping and flushing with water. In some portions of the East Indies, asphalt deposits abound, in fact, the supply of it seems unlimited.

As supplementary to our remarks on the cause of explosions in coal-mines, and greatly extending our knowledge of the subject, we give an abstract of a paper read by Mr. A. R. Sawyer before a meeting of the North Staffordshire Mining Institute, held at Stoke-upon-Trent towards the close of 1880. Mr. Sawyer is one of the British Government Inspectors of Mines. His paper related to an accident which occurred at the Fontanes Pit of the Rochelle Colliery, France, in July, 1879, showing that it was entirely attributable to a sudden and very considerable spontaneous expansion of carbonic acid which was present in the coal in a high state of tension, and which burst out into the main dip, hurling along and breaking up the coal which contained it. This was a new danger, which deserved the careful attention of everybody connected with mining. In what state was this gas contained in the coal? Was it, so to speak, intermolecular, or was it condensed under pressure in a cavity? The persistency of its disengagement in all the seams of the colliery led to the belief that its pressure was in an intermolecular state. Mr. Sawyer then proceeded to give some particulars taken from the report of the French Commission of Enquiry. He confined himself to that part of the report bearing upon the pressure and disengagement of fire-damp, on account of its reference to sudden outbursts, which might be applicable to the accident to which he had alluded.

"Although (he read) in the opinion of a large majority of practical men fire-damp pre-exists in the pores of the coal or of the surrounding rock in a gaseous condition, and subjected to greater or less pressure, the views of a certain number of engineers cannot pass unnoticed. They consider it as the product of disassociation at the last moment of very volatile liquid, or even solid compositions contained in the coal. This hypothesis has not as yet been borne out by chemico-scientific researches. Mr. G. Arnoult, engineer-in-chief of the Belgian Mining Corps, cites the following observations in its support :—The fact that fire-damp is soluble in water, as has been shown, appears incompatible with the properties of marsh gas ; the presence of certain hydrocarbons in the pores of the coal, which has been demonstrated by Messrs. Johnstone and Hutton ; the discovery of a large quantity of a brown substance in the pores of the coal, by Franz Schultze, which at first prevented the structure of the mineral from being made out ; a very volatile oil, which on being lighted produces a large flame, having often been found in company with Hatchetine (a mineral tallow) in the central cavity of nodules of siderite ; coal in fiery mines presenting sometimes a greasy and shiny appearance, which is almost immediately lost by exposure ; fiery coals, and especially bituminous coals, also losing their caking property pretty quickly when exposed to the air. The sudden outbursts which occur more and more frequently in the neighbourhood of Mons, causing dreadful accidents, would seem to corroborate this hypothesis. These extraordinary phenomena, already noticed by Mr. Devaux, have been described with the greatest care by Mr. G. Arnoult. They are always associated with the presence in the seam of a kind of combustible called *houile daloïde* in Belgium, and *fusair* at St. Etienne. This black substance is fibrous and powdery, and is nothing but charcoal remains either of arborescent ferns, sigillaria, or cordaites, which have preserved their structure. (See *ante*, p. 23). Bituminous coals often contain a pretty large number of layers of daloïde coal, producing in that case more dust and small coal. Accidents from sudden outbursts, unknown before 1847, even on an examination of official documents of as far back as 1818, are becoming more frequent every year, and seem to grow in importance with the depth. None have been observed above a depth of 280 metres. The greatest number have occurred at a depth of from 350 to 500 metres, but this must undoubtedly not imply a real maximum, for when greater depths are considered the number of mines decreases rapidly. Sudden outbursts have always been accompanied by a projection of a large quantity of small coal, which has sometimes filled the galleries for a distance of 40 metres, and whose volume has been as great as 420 cubic metres. Sometimes outbursts, instead of being sudden, are more appreciable. The phenomenon has often been accompanied by an intense refrigeration, and the pulverised coal has been found even after some time as cold as ice. This last circumstance would tend to meet one of the objections which have been raised to the non-gaseous condition hypothesis of fire-damp previous to its escape—the enormous refrigeration which would apparently accompany the volatilisation of such quantities of matter. But the mining engineer, Mr. Vicaire, has pointed out that certain substances, of which explosives are the most characteristic, instead of producing cold by their transformation, produce on the contrary an enormous amount of heat. Mr. Vicaire leans to the belief, *a priori*, that certain coals may approach this condition. He founds his opinion on the fact that their combustion produces more heat than does an equal weight of carbon and hydrogen. He also mentions that at St. Etienne cylinders of coal which were being compressed into fuel cakes and gradually heated became all at once incandescent spontaneously. In the Brassac coal-field it is carbonic acid, more than fire-damp, which issues out of the coal, but the question remains the same. Very marked effects of projection have been observed there ever since the last century, and Lemonnier, member of the Academy of Sciences, describes them in terms which still to-day are of much interest to those who are acquainted with that district. The explosion of carbonic acid at Rochelle in 1879, and certain analogous observations from the tertiary measures of Auvergne by Mr. Tournaire, Inspector General, may be attached to this order of facts."

CHAPTER II.

METAL-MINING AND METALLURGY.

THE art of working in metals, with the preparatory processes of smelting their ores, may be considered as one of the oldest practised by man. Both sacred and profane history treat on the subject; and our most remotedly dated antiquarian remains or specimens are so metallic in their character, that we can only assume the existence of absolute barbarism amongst those to whom the use of metals was unknown. With the ancient Greeks we have the tradition of the various metallic ages, as the golden, iron, &c.; but long before their existence as a nation, metal-working had been established.

There is little doubt but that the first use of metals was induced from their hardness or toughness, when compared with any other material. Flints, we know, have been, in very early ages, used as instruments for fashioning and shaping various objects for domestic and other purposes; and, at the present day, it is one of the most interesting questions of the ethnologist and antiquarian, to decide at what period any nation or people gave up the use of their primitive tools for others of a more enduring character. The Esquimaux of the northern region, equally with the New Zealander, must have been long acquainted with the use of metals in various forms. Strange to say (and as may be proved by reference to specimens in the British Museum), a great similarity exists, in shape and material, between the ancient Egyptian knives and those of the people we have just named. We were specially struck with this fact, on seeing some specimens of such articles, deposited at the British Museum, several years ago, by Mr. John Barrow, so well known for his steady adherence, with his father, Sir J. Barrow, to Arctic research. But very recently we were shown analogous specimens by Dr. Davidson, of the Antiquarian Museum, Montrose; and the similarity of shape, &c., in the tools used by inhabitants of regions as remote as geometry or geography could make them, cannot be accidental; it is highly suggestive of the unity of origin of the human race.

It is evident, however, that, except with trading nations like the Phœnicians, the manufacture of metals must have been extremely limited, simply because the sources of the ore would have been equally limited; omitting those countries in which metallic veins existed, or still exist. In respect to the Phœnicians and Romans, we have abundant evidence that, at long-differing dates (the former nation holding precedence in this respect), they both visited Britain for tin and lead. Hence, from our tin mines of south-western England, these islands became known among the ancients as the *Cassiterides*—a term derived from the fact that tin was here found (in Cornwall, &c.), as at the present day.

It is interesting to notice how the common sense of human nature selects that most suited to its purpose. Even in our day the savages of many parts of the world will part with their gold and most valued articles for a steel knife; and modern instances of the kind give us a kind of clue to the reasons that have made some metallurgical processes so highly progressive, by the aid of advancing science, in our day, when compared with the efforts of the ancients. Thus the art of working in gold, silver, brass, copper, and other comparatively soft metals, does not seem to have made any great progress, even if its condition equal that which existed two or three thousand years ago. But in respect to iron and steel, how great is the difference. The soft metals, with the exception of copper and brass, or other alloys of copper, were chiefly adopted by the early workers for ornamental purposes; and, doubtless, like the goldsmiths and other workers of the present day, "they got their own price." Not so with the "baser" metals, whose real value, however, has, from the earliest history of mankind, not depended on the caprice of fashion, but on the wants of humanity. Now iron, of all ordinary metals, is the most difficult to work, and yet the most valuable for all economic purposes, ranging from the knife of the kitchen or pocket, to the planing, punching, and other machines of the mechanical engineer. But, as we have already stated in our introductory remarks, at pp. vi and vii, *ante*, the working of iron requires a most intense heat; abundant and cheap fuel; and, above all, a knowledge of those chemical conditions, on attention to which the success of all metallurgical processes depends. Now none of these conditions have been satisfied until within a period not exceeding a century past; hence the slow development, in the early ages of man, in producing iron, compared, as we have already shown was effected, in working all the precious metals.

Another circumstance that greatly militated against extensive mineral and metal operations, in earlier times, was the utter want of mechanical appliances for removing or winning the ores. We have no evidence of shaft-sinking to any extent as having existed, until a compara-

tively recent day. At page vi we have pointed out that the early history of tin-mining was that of collecting, chiefly from the surface of the ground, but especially the beds of streams or rivers, the tin ore. We cannot suppose either laziness or indifference to have existed in the days of Egyptians, Greeks, or Romans; if so, whence the Pyramids; the Grecian models of architecture, now so esteemed and venerated; the aqueducts, Coliseum, &c., of ancient Rome; and the invaluable *reliques* of Pompeii and Herculaneum? It was simply a question of ignorance that prevented an extensive pursuit of metal extraction, especially in respect to iron. What could more astonish an intelligent Roman than to see a geological map of his country, of Europe, or of the world! And still more, how wonderful would it be to predict to such a person, that because certain strata are always found to be associated in certain parts of the world, the inference is safely to be gathered that, in an average of cases, such an association may be taken for granted in all parts of the earth's surface! Thus it was that the late Sir Roderick Murchison predicted the existence of gold in Australia, long before that existence became proved; and, for precisely similar reasons, the miner of our day feels so little doubt as to the probability of success in finding a vein of metal in any specified district, with the geological character of which he is acquainted, that he will unhesitatingly invest his own, or risk the investing of other capital in mining undertakings or adventures.

Imperfectly as we have pointed out the difference between ancient and modern systems of mining and metallurgy, our readers cannot fail to have discovered that some great cause must exist for such a difference. This we have laid at present to the prevalence of ignorance; and that want of knowledge was in respect to chemical science. A remarkable illustration of this is given at p. vi, *ante*, where we stated that the early Cornish miners were in the habit of throwing away the copper ore they discovered as of no value, calling it *poder*—a circumstance most fortunate for their descendants, who have reaped the profit arising from their ignorance. As soon as it was discovered that most ores are combinations of the metals with oxygen or sulphur, a new light burst on the art of metallurgy. The metallurgist, instead of going on in old systems, ignorant of principles, began to appreciate newly-discovered facts. If we do not get the metal native, because it is united with either or any other agent, elementary or compound, science and common sense point out that the removal of the latter is essential to our success. Hence the modern use of carbonaceous fuel, with lime and other fluxes, by which we eliminate from the metallic ores of the common metals all that renders them useless to us.

Much, however, as we may rail against the early workers for their slow progress, we may take much blame to ourselves. But a quarter of a century has elapsed since the first really scientific mode of producing malleable iron and steel (Bessemer's) was first brought into practical operation. The ordinary method of puddling, &c., is barbarous compared to the one just named; and has been practised, with but comparatively, in one sense, trifling modifications, for ages; indeed, so far as we can learn, from the earliest days of iron working. Again, although about eighty years have elapsed since Davy first discovered the method of decomposing potass and soda, and producing metals from them—followed by the discovery of aluminium by Wöhler, in 1827—it was so recent as 1855 before a process was applied, not essentially differing from the earliest adopted, but that at last gave us, from clay or other more suitable material containing alumina, a metal now extensively applied to so many useful and ornamental purposes.

Even zinc, cobalt, nickel, &c., may be similarly categorised; and we may sum up these remarks by stating, that metallurgy, as an art, has advanced more in the present half century, than during the whole period antecedent of man's history. This is chiefly due to the applications of chemical science to each detail, in the entire system of processes that are adopted at the present day.

In the first place, our means of analysis have become all but perfect. When, by ordinary methods, as by the wet processes of quantitative analysis, we can detect the presence of the $\frac{1}{100000}$th part, or, by means of spectrum analysis, discover the millionth, or far less proportion of a grain of a metal, our unpractical readers may gather some idea of what metallurgy has gained from chemistry. It was long known, for example, that manganese improved the qualities of steel; but an excess or deficiency above or below a certain and extremely small quantity, was absolutely harmful, or useless. Modern chemistry has, by its sure processes, found out how to give that exact quantity; and, at the same time has simplified its mode of application, rendering the same results uniform almost to precision.

Equally has chemistry been of infinite value in detecting substances of an injurious character in an ore, or in the fuel with which it is smelted. To avoid both these complications, at one time charcoal was exclusively employed for smelting purposes; and, of course, its expense was enormous; added to which, its employment, if adopted largely, would have soon cleared every valuable timber tree from the face of our island. Less than 200 years ago, "they once tried pit coal, but with bad success" (see *ante*, p. vii). Now the use of coal, in its mineral or coked form, is universal.

But chemical science has also been accompanied, in its application, with that of physics. The discovery of the doctrine of latent heat, by Black, laid the foundation of the invention of a workable, not to say perfect, steam-engine; and this result has had an enormous influence on mines and metallurgy. Formerly the minerals from a mine were either raised by horse or water-power. Animal power is, of course, extremely limited in its application, from the bulk of the animal, and the distance he must walk to perform a circle—say as seen in the horse-

mill. In respect to water-power, its use must be limited not only to the presence of a stream, but also to the constancy of its flow; and in our islands, practically, both these conditions are unattainable. Wind-power we need not mention, for that is as uncertain as its source.

When, however, the steam-engine was applied to mining and metallurgy, an entirely new era was inaugurated. The power it generates has no limit but the will of man. He can place a 500 or 5,000 horse-power steam-engine in a comparatively small space; and he can, with perfect ease, convey its power to a distance of 100 or 10,000 feet, for pumping, or any other purpose. By due precaution, as by erecting a pair instead of one engine, he can provide against almost every chance of stoppage in his work—a circumstance of common occurrence when water-power was employed. Whether he wish to sink a shaft, empty a mine, or convert the metal iron into ten thousand useful forms, his power is only limited by his capital; and, at the present day, this is all but illimitable, as applied to metal works.

But the simple production of power, as derived from the applications of physical science, does not stop here. Economy is of the greatest importance in all metal-works; for, as it is commonly said, we may pay too dear even for gold. It was therefore constantly attempted to reduce the cost of power; and this has been carried to so great an extent, that one pound of coal, as now applied in the steam-engine, is made to afford not less than four times the power (to say the least) it did in Watt's days, even in the most approved form of his engine. Thus the daily expenses of the miner and metallurgist have been greatly reduced; and although the modern consumption of coal is enormous, our present rate is low to what would have been required for the same amount of power used, had not economical processes and contrivances been invented, whether in respect to the working of the steam-engine, or other operations requiring that fuel. Formerly, all those who employed steam-power, and coal generally, in large quantities, for heating purposes, considered it a grievous infraction of their rights if they were disturbed or remonstrated with in making as much smoke as lay in their power. When, however, the consumption of smoke became compulsory, a great change came over the views of those individuals. To their great surprise, the severity of the law was not only good for their neighbours, but equally for themselves; and gradually it was discovered that much smoke led to great loss. Hence the adoption of smoke-consuming apparatus, that not only tend to improve the health of manufacturing towns, but to put, by saving coal, much money in the hands of the manufacturers themselves. Dealing here with the smoke question, we may add, that an immense quantity of sulphur, formerly wasted in smelting copper and iron ores by roasting in the open air, is now utilised, and has become a most valuable addition to our stores of that article in the manufacture of sulphuric acid. This has not only been thus lowered in price, but whilst the sulphur has been saved, the coal formerly used in roasting the ore so wastefully has also been economised; hence great pecuniary advantages have arisen, not only to numerous branches of manufactures needing the acid, but also, indirectly, to the community at large, for there are few chemical products so largely employed as the acid obtained by uniting sulphur with oxygen—the sulphuric acid already named; or, as it is known in commerce, "oil of vitriol."

It would be impossible, even briefly, to enumerate the importance of our mining and metallurgical processes in our home consumption, independent of our export trade. Those of our readers of from thirty to forty years' experience in life, will readily call to mind the enormous progress that metal manufactures have made in their development for domestic purposes, as well as in machinery; together with the great decrease in prices that has simultaneously resulted. Scarcely seventy years have passed since Bell started the first little steam-boat, of about three-horse power, on the Clyde (see *ante*, p. xvi), but now vessels working to 12,000 horse-power are common; and of less power than these we may reckon thousands, driving against wind and tide, on every ocean, and nearly every river of the world. To produce them, ponderous steam-hammers, drill, punching, riveting, planing, and other machines, have been, and are at work, all over this and most European countries. Sheffield and Birmingham wares are too numerous to catalogue, but are familiar to our readers in numerous details of daily life. But foremost amongst the occupations that absorb metals is our railway system, in the practical departments of which, as in locomotives, bearings, &c., &c., an immense quantity of iron, copper, tin, and their alloys, have been consumed since the year 1830, when we may consider railways to have been permanently established as a means of locomotion. See *ante*, p. xxvii.

Now all these applications of metals, and many that we have not mentioned, have not been simply made to pander to fine-art fancy, or elegance of taste; but, with barely an exception, they have been called forth by the wants of man impelling an industrial use of treasures of the earth, long existent, but slightly known. The Roman empire required, twenty centuries ago, the railway, the steam-boat, the machinery, the all-metal-manufacture of our day, just as much as we do ourselves in the British Empire. But the aim of life of the two nations must be judged from two opposite points of view. The Romans were proud of conquest; and their success in this pursuit engendered habits as fatal to nations as extravagance and luxury are to individuals. Our aim is exactly the opposite; for it is the object of all our political, industrial, and commercial institutions, to utilise what we have, rather than to rob others of what we have not. Hence in these spots of islands, compared to the area of the vast globe, we focalise an energy of self-independence on our own resources, that makes the rest of the world our debtors. If we may be permitted to use

scientific phrases in illustrating our meaning, ancient Rome was absorptive, whilst modern Britain is radiative. And, as we have already suggested, it is to the utilisation of our coal and metallic ores that our national greatness has been due—a utilisation resulting from force of individual and national education, by circumstances and experience.

These prefatory remarks will give some idea of the extent of the subject, an exposition of which, in its practical details, lies before us. To do complete justice to the matter in hand is simply impossible, even with the aid of the combined intellect of all who have studied, or followed practically, its principles and varied details. The different applications and uses of metals, at the present day, however, are so familiarly known, that if we err in omission, our readers may frequently, from their own experience, supply our deficiencies.

We may next review, in general terms, the characteristic qualities of the metals employed in industrial, art, and other processes. We shall find that the principle of selection has resulted in the full understanding of the qualities of each. Thus the practical chemist prefers, amongst the "noble metals," platina for his crucibles, the distillation of sulphuric acid, and other purposes in which it is requisite that he should have a material unacted on by the majority of substances that he has to employ. For art-purposes, jewellery, and ornamentation generally, gold and silver occupy, pre-eminently, the chief place. In extracting these metals from their ores, mercury, which is closely related, in its chemical characters, to the two preceding, is largely employed, for it acts as a solvent of these metals, forming "amalgams," from which gold and silver can be easily recovered by distillation; mercury, or quicksilver, being a readily volatilisable metal. Its fluid condition renders it susceptible of many other applications; as, for example, with tin, the "silvering" of looking-glasses, the construction of thermometers, barometers, and other instruments of philosophic or general use. Copper, and its alloys of brass, bell-metal, gun-metal, bronze, &c., being mixed with zinc and tin, or tinned over for domestic and other uses, as wire, sheet foil, &c., has extensive use. Its tenacity is great; it can be readily beaten or rolled, and hence is of great value for numerous purposes. Zinc may be similarly characterised; and, of late years it has come into great use for many adaptations to which lead was formerly devoted. We may more especially here mention its use for "galvanising," or protecting iron from the action of air and moisture. For this purpose it is, in most respects, far superior to tin, which, in many ways (at least, in the form of tin plate—*i.e.*, iron coated with tin), it has replaced. Lead is highly serviceable for numerous uses, being soft, pliable, readily melted; and hence, with tin, forms a valuable material known as solder. Tin is of great use for coating copper and iron good; as an alloy with copper in various "metals"—gun, bell, &c., &c.: in machinery it is of essential service, as a chief constitutent of bearings, diminishing largely the friction of rubbing surfaces, especially in various parts of the steam-engine, and its mechanical appliances.

In alloys of bismuth, antimony, nickel, &c., with copper and other metals, we have many valuable properties combined. Hence type-metal; also the German silver and Britannia metal, fashioned into numerous articles of domestic use. Manganese is of great value to the bleacher, as a means of obtaining chlorine in the manufacture of glass, calico-printing, &c., its characteristic qualities confining it to a limited use; yet, as before stated, it is a most valuable addition in the production of steel.

Iron and steel are, for the present, omitted; because we have already mentioned some of the most valuable qualities possessed by each; and so need not include them in the general review of the uses of metals.

Amongst other metals especially of use in the arts, we may mention chromium, cobalt, and arsenic, whose commercial values chiefly consist in their power of affording valuable pigments. Those of chromium give to the dyer and painter some of the most beautiful and permanent shades of yellow, orange, and green; the glass manufacturer also avails himself of this metal for the preparation of coloured glass; and artificial gems, of great beauty and purity of colour, are due to the fusion of silicious and alkaline matter with this and various other metallic oxides. In respect to cobalt, we need not remind many of our practical readers of its use in several arts as a pigment, and also for blueing purposes, as smalts, in certain manufacturing processes. Arsenic, as the arsenious acid of the chemist, or the "white arsenic" of commerce, has numerous applications: in agriculture, to prevent smut on wheat; on and in animals, for a variety of purposes; in the arts, combined with copper, as a most dangerous pigment, usually applied to paper-hanging, in dyeing, &c.; and, lastly, its most pernicious employment as a cosmetic, like some salts of bismuth, for "beautifying," but more correctly, ruining the complexion, and frequently the health of the individual having recourse to it.

Such is a very general view of the uses of some of our leading and common metals. Of recent additions to this class are aluminium and magnesium, that, in becoming of popular use, have created many benefits. Aluminium is peculiarly characterised. With a whiteness approaching that of silver, it has the great advantage of being scarcely tarnishable under all ordinary circumstances; it has a specific gravity not exceeding one-fourth of that of silver; can be readily worked into any form or pattern; forms alloys with copper, scarcely to be distinguished from gold; and, in fact, promises to become one of the most valuable additions that has ever been made to metallurgical art by chemistry. A few years ago its price was fabulous; and we had placed in our hands, in 1856, the first bar that was sent to this country, by the late Emperor of the French, whose enlightened patronage of science must be con-

sidered as the cause of the cheap production of this metal. It was kept with a great deal more vigilance than its bulk of gold would have received. Now it has a price of but a few shillings in the pound. "*Tempora mutantur*," &c. Magnesium equally, so far as quantity is concerned, with aluminium, depends on the cheap production of sodium, now at a price, per pound, less than one-third of that which we paid in our younger days for an ounce. Similarly, we may hope, by improved processes, that other metals, now chiefly known as chemical curiosities, will become not only abundant, but useful in the arts.

Each metal that we have named, and many others so rare as to be here properly omitted, have thus some peculiar property, on which its economic value depends, and which distinguishes it from, or associates it with, others in its various uses. We choose gold and silver for the making of "plate" and coin, because they, from rareness, have great pecuniary value; and, moreover, wear well, retaining long their polish when alloyed with copper. Although steel is susceptible of a high polish, and long retains it, still, we rather choose it, with wrought-iron, on account of its tenacity, ductility, and malleability. Copper combines, to a certain extent, the ductility, malleability, tenacity, and polish of each and all of the metals just named, either in itself or its alloys; hence the variety of its applications is very great. But some metals have, really or practically, no ductility, malleability, &c.; but still they have their uses. Antimony, for example, when alloyed with lead, or separately, has the peculiar property of expanding as it cools below certain temperatures, and hence exceeds all other metals in its applicability for making printers' types, or stereotyping. Zinc, again, under certain conditions, can, from some of its qualities, replace copper, iron, tinned iron, and lead; and hence, of late years, has been greatly used in our households, and in the arts, for many and various purposes.

In almost every instance, fusion (we do not here refer to smelting, the details of which, in respect to each one, we shall consider separately) is requisite to bring every metal into a workable form. The only exception that has ever practically existed to this rule has been in favour of platina, and that has now succumbed to the great heating power of the oxy-hydrogen blowpipe, first adopted on the large scale by M. St. Claire Deville, of Paris, to whom, under the auspices of the Emperor of the French (as before stated), we are indebted for the first attempt to produce aluminium on the large scale. Even iron, as cast-iron, is first in a state of fusion; and afterwards, although infusible by all ordinary means, owes its adaptability to all purposes to the primary condition just named.

Various degrees of heat, however, are requisite to effect the fusion of metals. One only—mercury, or quicksilver—is always in a fluid condition at ordinary temperatures. All the rest are solid under the same circumstances; and as we have just seen, there are some that require the greatest possible heat before their fusion can be effected. Two metals, in ordinary use, only have the property of welding; that is, of uniting together without any evident sign of fusion. They are platina and iron; and this property in the latter metal is of the utmost importance in its various applications; for, otherwise, wrought-iron would become practically useless, because of its infusibility. As regards platina, little difficulty occurs in welding masses of it, because it has no tendency to become rusty, or oxidised, even at the highest temperature, when exposed to the air. Not so with iron; this, as is well known, is rapidly acted on by air and moisture; and, at high temperatures, is so quickly oxidised, that great difficulty exists in keeping the surfaces clean that are to be welded together. If they are not kept thus clean, the joints must necessarily be imperfect; and hence, as in railway tyres, girders, &c., &c., a breakage has often taken place, causing serious, and frequently fatal, accidents.

The following are the melting-points generally assigned to the metals named, according to the scale of Fahrenheit. At the same time, in giving the table, we not only do not guarantee its accuracy, but must own that it would be indeed rare to find two estimates of metal-melting-points agree. Nevertheless, the table, gathered from various sources, and checked by several authorities, is quite near enough to the truth to be of service to the worker in metals. It is, perhaps, barely needful to remind any of our readers that the scale of Fahrenheit commences at a temperature of 32° below freezing-point, or 0°, also called *zero*; that the freezing-point of water is, therefore, 32° on his scale; and that the boiling-point of pure water, at the sea-level, is 212°.

Point of Fusion of Ordinary Metals.

			°
Mercury, below zero 40°, or . .			—40
Tin, above zero, or			+442
Bismuth	476	to	490
Lead	590	,,	630
Zinc			700
Antimony, just below redness.			
Brass	1750	,,	1870
Silver	1280	,,	1875
Copper	1990	,,	2550
Gold	2016	,,	2590
Cast-iron	1786	,,	3479

Now it must not be supposed that this is an actual variation, according to the scale of Fahrenheit, as stated in the above table, really existing between the temperatures thus assigned. The fact is, that when we arrive above the boiling-point of mercury, or somewhat over 650°, we have no certain means of measuring temperatures. The various kinds of pyrometers that have been invented to test the range of high temperatures cannot be depended on; for however ingenious their principle, in practice they all, more or less, signally fail. At the same time we must state, that the lowest temperatures given in the preceding table for the last five named metals, are undoubtedly the

most approximately truthful, having been made by an able philosopher, with, perhaps, the most philosophically constructed pyrometer.

Independently of the advantages that arise from the fusibility of metals in respect to working them, there is also the great one of our power to unite them as alloys ; hence fused gold, silver, and copper can thus be most intimately united, as can also copper with aluminium, zinc, tin, and other metals. It is by no means certain what the nature of an alloy is ; whether it is a mere mixture or solution, just like sugar in water, or a more intimate combination of a chemical character. Of late years, the latter opinion has gained ground ; and there seem many reasons to justify such a solution. For we notice that the physical proportions of such alloys greatly vary from those of the metals of which they are composed—a subject to which we shall draw more particular attention when alloys of various metals come specifically under our notice. The external appearance of an alloy greatly differs, in many cases, from that of its individual constituents: thus copper, alloyed with zinc, has a yellow colour, as brass ; a peculiar whitish-yellow with tin ; and a beautiful golden tint with aluminium, although each of the added metals has a shade of white, and, collectively, of the same colour, or nearly so. Often we find that the alloy is harder or softer than either of its constituents ; and thus, generally, the change of physical character is strikingly marked.

In respect to another effect of heat on metals, we may mention its power of rendering most of them volatile ; although this is only, with one or two exceptions, taken advantage of in metallurgy ; at all events, in connection with the ordinary metals—the exception being in the case of zinc. This is prepared from its ore by availing ourselves of its ready volatilisation. Mercury is similarly volatilised when employed to extract gold and silver from ores or a matrix not over-abundantly charged with those metals. Its union with other metals is termed an amalgam, as already explained. Arsenic, tellurium, cadmium, &c., are also volatilisable at comparatively moderate temperatures ; and, indeed, all metals can be volatilised by sufficient heat, as by the disruptive discharge of the voltaic battery.

We have already noticed that the requirements in respect to artistic ornamentation, and those of industrial processes, are usually of an opposite character in respect to the qualities of metals, although they occasionally coalesce in certain particulars ; as, for example, in the polish of the aristocratic gold and silver plate, jewellery, &c., and that of steel, used for more ignoble purposes. Before Sir Humphry Davy's discoveries, lustre, weight, hardness, &c., were all considered as essential qualities of metals; but those conditions, although partially resident in all metals, are by no means their distinctive characteristics. For example, take the question of lustre. When potassium and sodium are cut with a clean knife, they present an appearance as brilliant as polished silver ; but owing to the oxidating action of air and moisture, a few seconds' exposure dims, and at last destroys their lustre. In respect to tenacity, they have scarcely any ; but mercury has less : and in regard to specific gravity, they rank amongst the lightest bodies in nature. The quality of lustre is, therefore, comparative rather than real. But, commercially speaking, it is a question of great importance ; for nobody would buy rusty steel if they could obtain the polished article at the same price. Now, by a little care on the part of the manufacturer, this condition may be satisfied ; and thus Sheffield and Birmingham wares, whether of steel or other metals, have their character greatly dependent on their lustre. Unfortunately, this test of value is too frequently relied on in respect to the quality of the goods ; and the saying of the Latin poet, that the mind is better excited by the eyes than the ears, is falsified, in an economical point of view, in the case of purchasers of cheap plate, steel, and other similarly polished goods.

The amount of lustre, or rather polish, that can be given to metallic goods, depends on a variety of circumstances. As a rule, the most brilliant polish can be communicated to those metals that are the hardest in texture ; or which, in other words, most resist polishing operations. Steel, and the metal used for the specula of telescopes, are instances of the kind. But although these, through their hardness, are capable of taking so fair a polish, as we have already seen, they are exceedingly liable to tarnish from exposure to air or moisture. The exclusion of these influences, and the prevention of tarnish on readily oxidisable substances, is well shown in the common looking-glass. It owes its reflective powers to an amalgam of tin and mercury, *so closely adhering* to the surface of the glass, as to prevent the possibility of access of air. It hence preserves it brilliancy for many years ; yet the back of this surface, or the portion exposed to the action of the air, is almost instantly tarnished or oxidised. Similarly, a piece of steel, if supported in a closely stoppered bottle containing strong sulphuric acid, but not touching the liquid, will retain its polish for an indefinite period, simply because the acid, absorbing all aqueous vapour, prevents the possibility of its surface being acted on by the oxygen of the air or water.

But gold and silver, although so much softer than steel, attain a high polish ; and not only so, being barely acted on by external influences (never in the case of gold, and but by sulphur, in some form, in that of silver), are choice materials for art-production. In them we therefore notice that hardness is not the sole condition of lustre or polish ; for they are both comparatively soft metals, even if alloyed with copper or zinc.

Hardness, as a quality of metals, must also be considered in another light. When surfaces are subject to much attrition, and the amount of friction is not an object, it is always desirable to have a surface as hard as possible ; as, for example, in a file, razor, plane, &c., &c. One of the hardest surfaces that can be produced on metals is that occasionally seen in iron castings ;

and we have noticed such as capable of cutting good flint-glass. Of course, in the case of bearings for machinery, such a casting would be most injurious, for it would "cut" every metal revolving within it; and thus, although durable in the end, becomes very expensive. Iron, in the form of steel, and, to a certain extent, copper, are capable of various degrees of hardness. Steel, as we shall hereafter see, may be regulated to a nicety, in respect to this quality, by the art of "tempering" it; and more limitedly, by the addition, in minute quantities, of other metals such as manganese. The ordinary method of tempering steel depends on the addition or subtraction of heat on its broad principle. But heat is not the only force that can effect the hardness of a metal. We have frequently noticed, after even a moderate use of the best copper wire for voltaic purposes, that it becomes exceedingly hard and brittle; so much so, that we have broken a specimen, originally very tough, and of No. 10 B.W. guage, with the fingers at one bend, after such a wire had been employed to conduct the electricity of a powerful voltaic battery continuously for some time.

Hardness and brittleness are generally concomitant, simply because hardness is usually the result of a crystalline, and toughness of a fibrous texture, in all metals, but especially iron. We have seen pieces of cracked shafting, originally of excellent iron, which, when broken, looked as crystalline on the surface of the fracture as either zinc or bismuth. Iron shafting, and, in fact, all revolving articles of that metal, have a tendency to change their constitution, or rather the arrangement of their particles. This depends on certain changes, or motions producing those changes, which, in science, we call "molecular." Their practical result sometimes turns out most serious: and, to guard against accidents on railways, arising from such a cause, every railway carriage-axle has its "runnings" registered; and after a certain number of miles have been accomplished, the axle undergoes pretty much about the same treatment, in respect to heating, &c., that it required when first brought into its characteristic shape.

Elasticity is a quality of metals greatly depending on their hardness; because the latter quality is dependent on their molecular constitution. Of all ordinary metals, lead is the least elastic; and steel is that which most possesses this quality; hence its great use for springs of all kinds, from those of the buffer of the railway carriage, to those of the most refined spring of the watch. In respect to steel its elasticity, is controllable contemporaneously with its hardness by tempering; hence the various uses in which that metal is employed are connected with its elastic qualities. A perfectly elastic body, theoretically, regains its exact form after impact with another; but, practically, no body or substance exists naturally, or can be contrived artificially, that can fulfil such a condition; but for all practical purposes, steel arrives, if carefully manufactured, nearest to perfection in this respect. For example, we have the celebrated Damascus or Toledo steel blades, which may be bent point to kilt, and yet will, on the bending force being withdrawn, regain an almost perfect straight line.

There is no doubt that elasticity, like hardness, deteriorates, as a quality of any metal, by its power or quality being frequently exercised, or called into action, by any means whatever. Hence we find that, after the course of time, the springs of the common carriage, railway carriage, and watch, suffer fracture. The reason of this is easily arrived at. If hardness and elasticity both depend on molecular constitution, what affects one quality will equally affect the other; and, therefore, a similarity of result must arise from identical causes.

Tenacity is a subject intimately connected with the questions we have just discussed; but it is one of far too great importance to be here more than simply glanced at. Indeed, all the different qualities of metals are, at present, merely discussed generally and comparatively, so that our readers may, from first taking a broad view of each, be afterwards prepared to enter into more minute details. That tenacity must be a specific quality is evident; for metals bearing to each other a relationship otherwise very complete, differ essentially on this point. Take, for example, the question of specific gravity. Zinc and steel, lead and silver, gold and platina, &c., may, in pairs, be compared in respect to their tenacity and specific gravity, but it is evident that no relationship can be established on such a basis; although, if two metals nearly agree in respect to specific gravity, it is but reasonable to suppose that they must, to a certain extent, contain a similar number of particles, bulk for bulk, and weight for weight. But in the instances, or at least a portion of them, that we have named, another collective question may be considered; it is that of their chemical equivalents, or combining properties. These, in the case of iron, zinc, and copper, are exceedingly closely allied; and yet, like the element of specific gravity, they fail to afford any satisfactory reason why one of these metals should be more tenacious than another.

When we deal separately with the metals, we shall more minutely inquire into the condition or quality of tenacity, both relative and absolute. Of course, it is intimately connected with the qualities of malleability and ductility; or the rolling and hammering into sheet and foil, or drawing of wire—operations on which depend the major portion of our metal manufactures, and all the economical applications to which they are put. These qualities have, therefore, been carefully investigated by some of our most eminent modern engineers; and the results of their researches, so essential in connection with ship-building, the construction of bridges, &c., &c., will demand our careful attention.

Of minor importance in some respects, but in others highly important, is the question of colour. For this quality gold has the preeminence in regard to yellow; whilst silver is equally esteemed for its white, so far as metals

can be denominated. Many intermediate tints between metallic white and black, yellow and green, or bronze, &c., are obtained by processes chiefly of a chemical nature, and that afford a most pleasing variety in metallic ornamentation. Even amongst the lower kinds of metals, some effective results may be obtained by chemical or mechanical processes; as, for example, the production of a crystal-like surface on tin plate; the "bronzing" of gun-barrels; the lacquering of brass, &c., &c. Silver presents a very effective result by the contrast of a frosted and polished surface; and by depositing, partially or entirely on its surface, platina as a fine black powder, some very good effects are also afforded. Copper is susceptible of producing, with gold, aluminium, and zinc, all shades varying from yellow to a dark orange, approaching a red; it having, individually, a colour of the latter-named tint, unequalled and unmatched in any other natural production. Unfortunately, its colour-proper is very unstable—heat, air, moisture, &c., speedily altering it to black, from green, yellow, and numerous other mixed tints. We have already noticed the various effects that the alloying of zinc, aluminium, and tin, has upon copper in respect to the production of colour.

It is beyond our scope here to speak of the effects of colour produced by metals, or rather, chiefly by their oxides, in glass-staining, and enamelling. Suffice it to say, that in these arts, metallic oxides are not only essential, but the sole cause of the colour produced. Much experience is required in their application to such purposes; and, in skilful hands, the effects almost equal some of the best productions of nature in the form of real gems. The emerald, ruby, garnet, topaz, and other favourite gems, have thus been most successfully imitated; so much so, indeed, that factitious productions have, in numerous cases, been passed off as real gems—of course, to an inexperienced person, in most instances, as there are certain qualities in the natural article that art fails to imitate successfully.

We may here notice, that while the metals generally are, with the exception of gold and copper, of a white, or bluish-white appearance, and hence possess a certain amount of monotony, their combinations with other bodies, as oxides, salts, &c., present some of the most beautiful, and the finest colours imaginable. Thus the combination of gold and tin has the richest purple when precipitated from their solutions. Mercury and iodine give fine shades of yellow, and a beautiful orange-red. Copper is generally characterised by greens. Chromium affords a green, and, with lead, various shades of yellow to orange. Arsenic gives reds, yellows, and greens, by various combinations with sulphur and copper. Vermilion and cinnabar are mercurial compounds. Lead affords us red lead, massicot, &c.; and generally its combinations with oxygen run in colours from yellow to orange, or shades of red. Cobalt is readily recognised by the blue of its "smalts." Tin with gold, in giving purple, has been already named. Manganese gives a rich purple to the glass-stainer, imitating the amethyst, when diluted. Zinc we can say nothing of in respect to its colour-producing properties, except that its oxide may be, from its pure white, substituted for white lead. Bismuth is similarly to be mentioned as the source of that pernicious cosmetic "pearl-white." The salts of nickel resemble those of the protoxide of iron, being of a green colour; but much richer than those of the last-named metal. Iron has a coarse red oxide, well known in the form of plate-powder; but, with cyanogen, it affords the splendid colour and pigment called Prussian blue. For the present we omit mention of the colours afforded by the rarer metals, as uranium, &c., &c.

Practically, there is but one metal that has been turned to account because of its inflammability, directly as a metal; and that is magnesium, now produced in large quantities. We have heard much of its value for likeness-taking at night; but believe that no sensible person would submit to be caricatured by such a nonsensical and unnecessary stretch of chemical science. In the case of photographing a corpse, which could offer no objection to the process; of the contents of a museum inaccessible to light; and, as has been done, the production of a view of the interior of the Pyramids, the use of the magnesium light is beyond estimation in its value. What further application may be made of it, of course we cannot prophesy; but it has, in use, the same objection as that incident to the electric light; and this is a great want of the power of diffusion. In pyrotechny, the salts of strontia for a red; of baryta for a green; zinc, iron, antimony, arsenic, &c., are of constant use. And here we may again notice one of the most wonderful discoveries of our era—that of spectrum, or spectral analysis—which, by utilising the characteristic colours of inflammable metals, has placed in our hands an analytic power far exceeding, in minute accuracy of its results, anything that chemistry previously put us in possession of.

The general chemical character and relation of the metals, is a subject that must be left to the detailed account of each, because it is too extensive to be here even briefly epitomised; suffice it to say, that their chemical combinations *inter se*, and with other bodies, afford results of the highest importance in the arts, and industrial occupations of man, second only to such as arise from their peculiar character in the metallic form.

Of late years, the metals have had an extended influence in art-productions, arising from the application of the laws and processes of electro-chemistry. The results thence accruing have been of the highest value. At the present day, almost the poorest in the land may have at his table a plated spoon, fork, tea or coffee services, equalling, or rather excelling in beauty, and in all qualities but that of durability, the real article of gold and silver plate. But durability is fairly no question, in a process so easy of renewal, in cases of wear and tear. Formerly, the Sheffield plate was the only and

expensive substitute for the real plate of silver, excepting the German silver and Britannia metal, which are greatly inferior in character. The Sheffield plated goods, however, were hideous when much worn, presenting a dark-red copper surface at the worn edges, in contrast with the white silver.

As electro-metallurgy is a subject that requires a separate chapter to do it justice, it would be out of place in this part of our work to do more than give general outlines. It will be fully dealt with hereafter.

Formerly, if it were desired to overlay a common with a finer metal, numerous artistic processes were had recourse to. In respect to gilding and silvering (and, in the latter phrase, we do not allude to the silvering of looking-glasses), which was more generally termed plating, both chemical and mechanical processes were adopted. For example, there was the method of *water-gilding*, by which gold was dissolved, or, more properly amalgamated with mercury; and in this state of suspension it was applied to copper and other surfaces. By aid of heat the mercury was driven off, and the gold remained affixed to the baser metal. Gilt buttons, and other similar objects, were thus manufactured.

Sheffield ware we have already alluded to. It is formed of copper, on which a silver plate has been soldered. When this double plate is rolled out, of course a more extended silver-copper surface is obtained. This forms the material for teapots, candlesticks, &c., &c.; and, at one time, was the only substitute for silver manufactured from the solid metal. The edges, as already noticed, soon wore out, presenting a most unsightly appearance. This was partly obviated by soldering an extra amount of silver at those parts where the most wear would be effected. But still, in course of time, the objects thus produced become unsightly; and having no intrinsic value beyond that of the copper, of which they are chiefly formed, cause great loss to the purchaser. This may be partially mitigated by the sale of the little silver left on their surface to the refiner, who, however, always has the best of a bad bargain.

But, by aid of electricity, all these sources of loss, annoyance, and unsightliness have been obviated. Thanks to the discoveries of Faraday, since amplified by other eminent experimentalists and practical men, we are now able to throw down a coating of the precious metals instantly, and with the most perfect ease, which, if not so durable as the same metals alloyed with copper, and generally used for plate or coin, yet has the advantage of being renewable to any thickness, according to the wish of the individual requiring its use. The principles and practice of electro-metallurgy may thus be epitomised; for, as we have stated, we cannot here enter at length into the details of this most interesting and useful process, which will afterwards be fully explained and illustrated in its most minute details.

Formerly the Voltaic battery was exclusively used in electro-metallurgical processes. But now the electro-dynamic machine has replaced the chemical battery. It can be kept in action for an indefinite period, causes no nuisance, and in every respect supplies the electric force necessary for electro-deposition of gold, silver, copper, nickel, &c. One form of such machines as employed in the production of the electric light has been already illustrated at p. lxxxii *et seq.* in our introductory remarks. In the following cut (Fig. 76) is an illustration of a room in which the process of electro-gilding is carried on. At the top may be seen the wires, by means of which the electric current is brought either from the voltaic battery or the magneto-electric machine. Right and left are the troughs in which the articles are gilded, and sundry vessels for washing and other purposes are also shown.

It is astonishing how this method of depositing metals has become of extensive use of late years. The earliest patent that we are aware of was taken out in 1836, and was, of course, followed by many others, either as improvements or modifications of the first. But some time elapsed before electro-silvered or gilded articles got into popular use. At first, the better class of society regarded the method with disdain; and others had too long been unused to gold and silver plate to desire such vanities. Now, however, the art has so extended, that the articles thus produced may be found in almost every household. They have replaced the well-known German silver, pewter, Britannia metal, and such goods that were frequently dangerous, from acids, &c., acting on them; and by the taste evinced in the designs of the articles now supplied by the better class of electrotypers, an almost educational value may be assigned to the pursuit of the art, and its results. One of the most important of the applications of electrotyping, is that of the reproduction of wood blocks for the illustration of printed works. Formerly the wood block was placed on the press; but it was soon worn out. At the present time, electrotyped copies are taken in copper, which can be renewed as often as desirable from the original. It is by such means that the majority of the illustrations of all printed works, at the present day, are produced, and that at a comparatively trifling expense, to what was formerly incurred.

Incidentally with this application of electricity, it may be remarked, that currents of electricity have been noticed as produced in veins of metals in certain mines; and many curious speculations have resulted to account, on electro-chemical theories, for the production of such veins. But the subject is in far too crude a state to permit the least reliance on the conclusions that have been drawn; and we have no hesitation in excluding them from a place in this work.

We may suggest, however, a very simple and easily-tried experiment, by which, to all appearances, a small vein of metal, resembling that seen in mines, can be produced, and which we accidentally discovered about thirty-five years ago. To a certain extent the result countenances the theories above alluded to; and certainly natural circumstances are remarkably

well imitated. The following directions will enable our readers to repeat the experiment :—

Take a small common red porous garden-pot, six inches deep, and half fill it with plaster of Paris; which may be done by stirring the powdered article, sold in the "Italian shops," with water, in a basin, and then pouring the mixture, which should have about the consistency of paste, into the pot. It will soon "set," or become solid. Then solder a piece of copper wire to a piece of zinc and copper sheet, each about an inch square, and fixed at the extremities of the wire, that should be about a foot long. It must be carefully covered with sealing-wax, to prevent it coming in contact with the liquids that are employed. The pot is then to be left for at least three weeks, at a temperature not less than 60°, easily attained in summer or

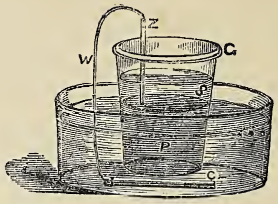


Fig. 77.

Fig. 76.—Electro-gilding.

be placed in a basin or dish, as shown in the above cut, Fig. 77, sufficiently deep to reach at least as high as its margin to the upper surface of the plaster of Paris in the garden-pot. Then bend the wire so that the copper, C, may lay at the bottom of the basin, B, and under the pot, G. The zinc then is to be inserted so as to touch the plaster of Paris, P, in the pot. A strong solution of sulphate of copper, to which a little sulphuric acid has been added, is to be poured into the outer basin, B, as high as the level of the plaster of Paris in the garden-pot; and inside this pot a solution of common salt is to be poured, as at S in the cut. A cover should be put over the whole arrangement, and it must autumn, but must be sustained artificially in cold weather. At the end of the time named, the pot may be removed, and the plaster broken. In our most successful results we have obtained metallic copper in nodules and crystals, exactly resembling specimens of native copper, as seen in the mine: these were interlaced occasionally with various layers of purple and blue streaks—most probably a carbonate, perhaps resulting from the presence of chalk in the plaster of Paris used. We give this experiment, not as any proof that mineral veins result from electro-chemical action, but simply as affording a result mostly coinciding in appearance with that found in nature. By modifying the arrangement, we

have obtained tin in the most beautiful crystals, using a solution of sal-ammoniac and a little hydrochloric acid in place of the previously-named solution of copper, &c.

Last, and amongst the most important of the general qualities or character of metals, we must more particularly draw attention to the question of specific gravity, which is one of great interest in a philosophical and practical point of view. In general terms we have previously alluded to it in connection with other qualities of metals. But, of course, all solid bodies are subject to such relations of bulk and weight, whether they are gaseous, liquid, or solid.

Specific gravity, indeed, depends on the relation that subsists between their ratio of bulk and weight. Thus if a bulk of water weigh one pound, the same bulk of platina would weigh about twenty-one pounds; but an equal bulk of atmospheric air would only weigh the 820th part of a pound, or about nine grains, reckoning by avoirdupois weight of 7,000 grains to the pound. But as we have now only to deal with metals, we may state, that although they vary much in specific gravity, still such variations is within very much narrower limits than those just indicated.

The lightest metal, the specific gravity of which has been correctly ascertained, is potassium, eighty-six grains of which are equal in bulk to 100 grains of water. As we take this liquid at 60 or 62 Fah. for a standard of solid and liquid specific gravities, and call it 1·, 10·, 100·, 1000·, or so on, to suit the decimal estimates or fractional value of other substances, we should indicate the specific gravity of potassium as ·86 decimally. The heaviest metal ordinarily met with is platina, the specific gravity of which, in reference to water, is 21·0. Thus we see that, bulk for bulk, platina weighs about twenty-five times as much as potassium.

The method of obtaining the specific gravity is very simple, although it requires several precautions to be observed, if extreme accuracy be desired. It depends on the fact, that if we first weigh a body heavier than water in air, and then ascertain its weight when immersed in pure or distilled water, it will, in the latter case, lose as much weight, so long as it is so immersed, as is equal to its own bulk of water; for, of course, it must take the place of this in the vessel containing the liquid. This necessarily follows from the fact, that although a cubic inch of all metals must measure the same, they will not weigh the same. Therefore, if we could form exactly a cubic inch of each, and weigh both in air and water, although exactly the same quantity of water would be displaced by each under such a circumstance, still the ratio of the weight of that quantity to that of the metal would be variable, and depend on the density of each metal.

It would be, however, simply impossible so to form an exact cubic inch; we therefore proceed as follows:—Having weighed accurately the body in air, and then in water, the weight in the air is to be divided by the difference between that and the weight in water; the quotient is accordingly the specific gravity of the substance under examination, in relation to water as the standard.

It will be unnecessary for us to give any extended table of the specific gravities of all the metals, because, practically, but few of them come into ordinary commercial use; and such as we omit are either of comparative rarity even to the philosopher, or are employed in such small quantities, or for limited purposes, as to be here omitted. Amongst the most important are the following:—

Specific Gravity of some Metals; Water = 1·000.

Aluminium	2·60	Iron	7·50
Antimony	6·80	Lead	11·45
Arsenic	5·88	Mercury	13·50
Bismuth	9·82	Nickel	8·70
Chromium	6·00	Platina	21·00
Cobalt	8·54	Silver	10·50
Copper	8·29	Tin	7·25
Gold	19·26	Zinc	7·15

The above figures do not express the specific gravity, in relation either to water or each other, with absolute correctness, for many circumstances tend to modify this quality of metals. For example, cast metals are, as a rule, lighter than those that have been hammered, rolled, or drawn, because all these operations have a tendency to bring the particles of a body, but especially a metallic one, in closer contact. Now we cannot tell whether each particle of two different bodies may vary in size, weight, or distance from each other, to cause a difference between the two in respect to their *absolute* specific gravity. But, *relatively*, between a cast and a rolled specimen of the same metal, we can have no doubt that the mechanical agencies employed have a direct tendency to reduce the distance between the particles. This conclusion is arrived at for two reasons—first, because we can ascertain that the rolled or hammered specimen occupies less space than it did previous to such operations; and, secondly, that during such operations, the heat, previously latent or lying hid, is rendered sensible by the mechanical disturbance or compression of the particles. Thus, if air be compressed in a syringe, of a suitable character, so much heat is produced as to ignite a piece of tinder; a nail, if repeatedly struck on a cold anvil by a cold hammer, will afford sufficient heat to ignite a sulphur-match; in boring gun-metal, working the punching machine, and many other such operations, in all of which the compression of the particles of the material occurs, heat is evolved. These facts being admitted, they may be checked by another and opposite method. Thus, if we artificially heat a metal we diminish its specific gravity, as may easily be proved by a simple experiment that suggest itself; whereas, if we cool it below the standard, say 62°, we increase its specific gravity, relatively to water and other bodies. Hence the reason of a rolled or hammered metal having a greater specific gravity than a cast one may be readily perceived.

The practical application of the laws of specific gravity, and their importance, may at once be understood from the following considerations. Supposing, for example, that it was required to line a cistern with a metal that should be sufficiently durable to last a few years. Two metals would at once be suggested, either of which might be used for the purpose : they are lead and zinc. Suppose, again (which is impossible, because of the want of tenacity in lead), that a sheet of each could be rolled to exactly the same thickness, and that, in all conditions, they should be equal in respect to wear, &c. We should find that the lead lining would weigh as 11·45 to 7·15 (see table of specific gravity, already given) ; and $71\frac{1}{2}$ pounds of zinc would cover as much space as $114\frac{1}{2}$ of lead ; or, in other words, the lead would weigh, in round numbers, $\frac{114}{71}$ times as much as zinc ; and reducing this to its lowest proper value, we should have the ratio of the weight of the zinc to the lead, as 1·0 to 1·6 ; or the lead would weigh two-thirds heavier than the zinc. Now, the average value of sheet lead per ton, to sheet zinc, is as 21 to 28 ; or zinc is one-third higher in price than lead. But the same bulk of lead weighs two-thirds more than zinc ; hence, of course, the employment of lead, according to the law of specific gravity, would cause considerable loss. But all our practical readers know that it is impossible to roll lead to the same thinness, giving an equal strength with zinc ; therefore, we have considerably underrated the ratio, in respect to the increased cost of lead, for our supposed purpose.

Our illustration of the commercial importance of the law of specific gravity has been on the most trifling scale. Applied, however, in the construction of bridges, railways, &c., &c., it is a question involving thousands of pounds. It has also another value ; for, although the amount of metal put into any construction may be approximately ascertained by taking an account of all quantities supplied, the result may be checked by a knowledge of the specific gravity, combined with that of the bulk. Timber, stone, and brick bridges may have their weight very nearly arrived at ; for, by first finding the specific gravity of the material employed, or its weight per cubic foot, it only remains to multiply them by the cubic contents, to arrive at the close approximation of the total weight of the erection. Similarly, the law is applicable to all other solid material.

These remarks will show how important a knowledge of certain scientific principles is to the practical man. In the absence of such knowledge he frequently gets much astray, and may often sustain considerable pecuniary loss. The apparent "littles" in life make or ruin men, according as they are attended to or neglected.

Having thus given a general account of the peculiarities of metallic bodies in their physical, and some chemical relations, we pass on to consider the nature of ores, and the methods adopted in mining for metals.

Practically, ores and native metals may be divisible into two classes—those that are found on the surface of the earth, and such as are imbedded in rocks, strata, &c. In the eye of science, however, they are not so divisible, simply because the two preceding conditions are more accidental than real ; or at least one of them must be so. For example, we may take either tin or gold, both being found in alluvial beds, and yet equally derived originally from strata peculiarly identified by their presence. The reason that they are thus found in what we may term a double position, is that resulting from the action of causes external to the natural condition of the ore or native metal ; and that arise from the effect of disturbing forces incident to what, for the present, we may term geological conditions.

Stratified rocks are generally characterised by the presence of some kind of metallic oxide ; in fact, we cannot practically separate them from that condition if we adopt the broadest signification of metallic presence. Let us take for a moment a glance at the coast-line of our own islands. In the far north of Scotland, and proceeding towards the borders of England, we notice continually the presence of iron, as a metallic oxide ; calcium, in the form of limestone ; and flint, which may or may not be considered as related to metals ; independently of what we may properly term metallic veins or lodes, of which we shall shortly have to speak more particularly. A great mistake exists in the supposition that the only metal which exists in a stratified rock is that which is most used. In fact, mountain limestone generally (the matrix, at all events, of lead) contains an infinitely greater amount of metal in the form of calcium than of lead, or any other ordinary metal. Our conventional ideas of metals, and the commercial requirements of our time, limit us. Had chemistry the power of reducing chalk, that contains twenty parts of calcium in every fifty of its weight, the cliffs from the Reculvers in the Thames, to Dungeness, and the strata thence to Whitby, in Yorkshire, would yield more metal than all the mining operations that have been carried on since the days of Tubal Cain ("an instructor of every artificer in brass and iron"), to the present day, have afforded. How great a field, therefore, lies open to the experimentalist and practical man. But we must now return from the suggestive to the practical in respect to the ores of metals, and the methods adopted in obtaining them ; although our digression is fully justified by the comparatively recent production of magnesium and aluminium in quantity, as already mentioned.

Generally speaking, all metals in the ore state are found combined with other substances, such as oxygen, chlorine, iodine, bromine, sulphur, phosphorus, fluorine, selenium, tellurium, &c. ; but the actual range of workable ores, apart from native metals, may be restricted to *oxides*, as those of iron, copper, &c. ; *sulphides*, or combinations of sulphur with the metals generally called *pyrites*, of which iron, copper, and lead form the chief illustration ; *carbonates ;* chlorides more rarely ; and still more so the other

combinations already indicated. Arsenic is often associated with metals; and such combinations are seldom of much value in a commercial sense. At the same time they become valuable in certain instances. In any metal combined with another substance to form what is generally termed an ore, it is of the greatest importance that we can quickly get rid of the substance with which the metal is combined. Thus, if we have to deal with copper, iron, and lead pyrites—that is, their combination with sulphur—this latter substance presents but little difficulty in being got rid of; indeed, its presence may become a source of considerable commercial profit.

A curious instance of the value that may result from a careful application of chemical science in the treatment of ores, arose not many years ago. The Cleveland district of the present iron production was then all but valueless. The ore was, as dealt with according to the established, and, we may add, the prejudice-established system, useless. But, by recent and more careful experiments, methods were discovered by which the produce of that district has become the most valuable in England; indeed, for its area, it is perhaps unequalled in the whole of Europe.

Taking our method of dealing with ores in the result of reducing the metal, we must confess, that although the progress made has been comparatively rapid, it is really, in the absolute, a discredit to science. The present processes are incomparably slower than we follow in the laboratory; and, at all times, the latter should be made the guide of the practical man, although he may never attain its proficiency, simply because he cannot arrive at that exactness of proceeding which is characteristic of the chemical workshop. Those who have travelled, using a scientific eye, in districts where our iron manufacture (*i.e.*, smelting) is carried on cannot but regret the enormous amount of waste resulting from that operation. Does prejudice, local or manufacturing interest, prevent improvement? We almost fear that what has been urged against workmen's associations, may, in this respect, be equally directed against larger and far richer combinations; and thus we have every reason to believe that the reduction of many metallic ores in the country is not dictated with that economical view which is characteristic of our textile manufactures. The fuller consideration of this question, however, may be more conveniently deferred until we enter into the details which attend the production of metals from their ores, so far as this country is concerned.

It is a matter of great importance, in dealing with the ores of metals, or even those which we find native, to have available all the mechanical and chemical contrivances, appliances, &c., that are essential to their reduction. For example, there are instances of metals (we refer to copper) being so pure as to be utterly unattainable for commercial purposes. A few tons of copper so circumstanced, may cost more to detach for commercial purposes than the results would fetch in the market. This occurs in some parts of America, and, we believe, also in Australia; hence the mechanical condition of an ore is one of great importance. It would by no means be impossible to find, in the localities we have mentioned, masses of copper so pure, and, therefore, so tenacious, as to be of the utmost value; and yet, in their removal, almost valueless. But this rarely occurs; in fact, the opposite condition generally prevails; and, in England, restricting ourselves to copper for the moment, the question of pecuniary consideration lies in the comparative poverty of the ore. Generally, throughout the British Isles the same condition prevails.

Rarely does an instance occur so favourable for mining purposes, in a chemical or commercial point of view, than that we find in the black band of Scotland, extending from the Lothians to Ayrshire. "The black band of Scotland varies from fifteen or twenty inches to five feet in thickness, and resembles the black shales common in coal measures. It is widely spread, easily calcined in heaps with waste coal, and, when roasted, yields as much as 60 per cent. of iron in calx, readily melted in the furnace." This remark refers to the singularly adapted chemical and mechanical conditions, in which the ore, its flux, limestone, and coal are all adjacent; and, indeed, are found assembled together in digging one pit or driving one shaft.

In Great Britain (to which, of course, we must chiefly direct attention), metal-mining has but little variation, in its details, from that pursued in coal-mining, if a shaft must be sunk. But a great difference exists in the thickness, direction, even character, &c., of the veins, lode, &c., arrived at. We have already stated that a coal-bed have several feet in thickness—even that of fifty feet has been discovered. (See page 5, *ante, et seq*). In England coal-beds attain a maximum of not more than forty feet—greatly exceeded, occasionally, in other countries. In the case of metal-mining, we may reckon the maximum nearer in inches than in feet. The distribution of a metal in a vein or lode, greatly differs from that of coal; it is much more irregular in one sense, and less so in others. Occasionally, in place of shaft-sinking, an adit or horizontal shaft is driven into a rock on the side of a hill. An instance of one of this kind is represented in Fig. 78. This method of mining is common in the case of lead mines. The sides and roof are supported by planking; through which, however, the water readily percolates, to the annoyance of the miner, and especially of the better-dressed visitor—a fact that we can corroborate from personal experience. The entrance represented in our engraving, Fig. 78, is of much more imposing aspect than some that we have visited; one of which we have an especial recollection of, situated not far from Richmond, in Yorkshire. It may interest some of our readers if we give a brief description of a visit to the lead mine we now refer to, made about thirty years ago. A party of ladies and gentlemen was made up for the purpose of exploring its recesses. At the entrance each person was furnished with about a twenty-to-the-pound dip candle, the only holder

for which was the fingers. The top and sides of the mine were composed of what we can only call, in common language, a yellow dripping

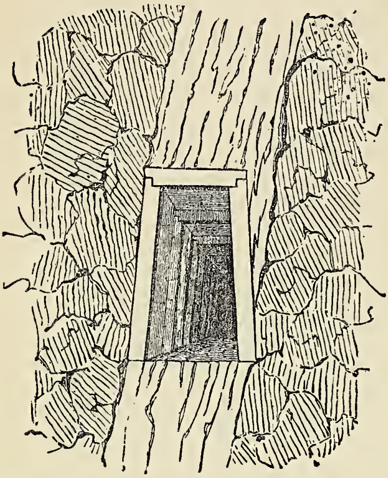
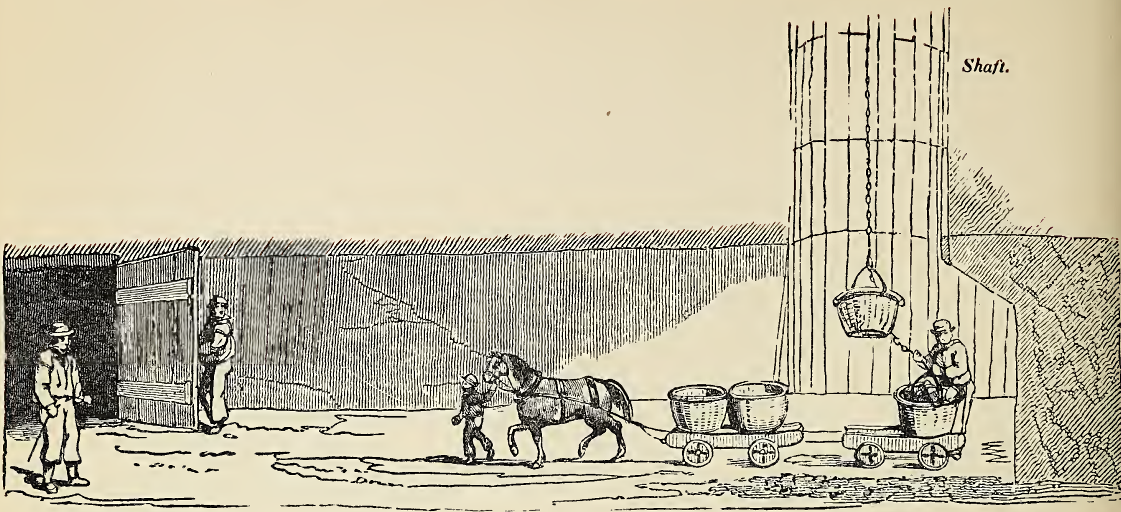


Fig. 78.—Horizontal Gallery of a Mine.

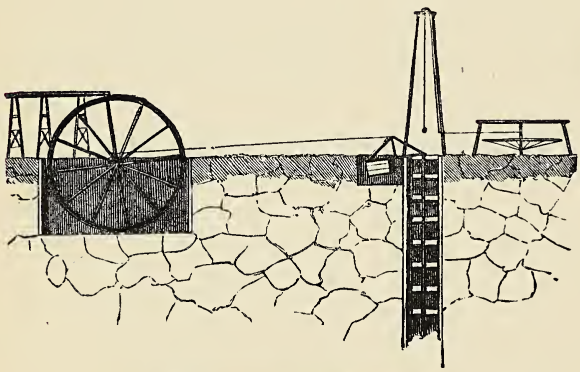
clay. Used to mining adventures, and in the absence of any proper dress, we removed coat and waistcoat, and put on a sack; but the ladies of the party insisted on entering the adit with white muslin dresses. The adventure was not without laughable incidents. Scarcely had we passed through a distance of 200 yards—the adit having a width of about four feet, and an average height of three to five feet—than one of the ladies thought proper to show signs of fainting. The tendency was immediately dispelled by informing the lady it was impossible to return without turning round, which, until the end of the adit was reached, was quite out of the question for the whole party, considering that most of them were of the full average height of man. Mud, dirt, close smell, &c., &c., were surmounted, and at last the end of the adit; and, simultaneously, a very rich lode rewarded the exertions of the amateur miners. The return was more readily effected; but, at the exit of the party, our lady readers may guess, but could scarcely describe, the remarkable result which about half a mile of dripping clay effected, in two hours, on the white dresses and the black coats of the visitors, independently of the drippings of the tallow candles that had been held in the fingers of each of them.

Some years ago, in a visit for geological purposes in Derbyshire, we had a narrow escape from falling down a deep, long, but narrow "slit" in a rock which had been left by the ancient lead miners. The following illustration (Fig. 79), represents a mine called "Odin's mine," which

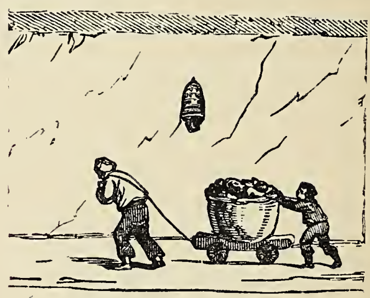
Fig. 79.—Entrance to the Mine of Odin, an ancient Lead mine in Derbyshire.



VENTILATORS. CORVES ABOUT TO ASCEND THE SHAFT.



WATER-WHEEL OF A MINE.



DRAGSMAN AND FOAL.

PREPARING TO BLAST. GATHERING THE COAL.

WORK IN A MINE.

is believed to have been worked ever since the time of the Romans. It consists of two horizontal levels or galleries, the upper one of which serves as a channel for bringing away the ore from the mine, and the lower one for drainage. The workings have been carried above a mile into the heart of the mountain.

The methods of removing and raising ores by vertical or sunk shafts, pumping water from the mine, blasting, &c., in respect to metal-mining, are precisely similar, in all points, to that we have already described as relating to coal-mining, especially as regards iron ore. The descent into a tin or copper mine, as found in Cornwall, is a very different affair, owing to the peculiarity of the strata, the run of the vein, and other circumstances. Thus the mine is often reached by a series of ladders, and not, as in the case of coal mines, by descending a shaft by means of a cage or corve, as described at p. 9, *ante*. The following description of a descent into a Cornwall mine, where tin or copper is extracted, will give the reader some idea of the nature of the operations carried on, and the hardships and difficulties attendant on them. It is one originally published in the *Mining Journal*, and quoted by Dr. Ansted. Its truthfulness we can vouch for.

"Mines are not all equally wet; but no one can expect to penetrate very far into a mine, and emerge dry from it. We have therefore to go to the 'shifting-room,' and attire ourselves in a miner's garb. It consists of a suit of thick flannel, with a stout coat over it; heavy shoes for the feet; and a hat, generally made strong enough to 'bear a good knock.' We must also provide ourselves each with a candle. The candle is stuck into a piece of clay, which again is stuck upon the hat, generally of the 'wide-awake' shape. Thus equipped, we descend the ladders. As we approach the shaft, we perceive a steam rising from it. This, we were informed, is the breath (or rather the moisture from it) of the men at work below. The very mine itself seems to breathe. There are at least 600 men at work beneath our feet, at various depths—some 100, some 500, and others 1,600 feet. The ladder is very narrow, has iron bars, and is well-nigh perpendicular. The bars are moist and greasy, from the men passing up and down, which makes us cling all the more firmly, considering the unknown depth of the shaft, and the almost perpendicular position of our means of descent. We bid adieu to daylight almost at the time we have reached the first level. There is no one at work in it, so we descend to the second. We pass it, and several others, until at length we reach the seventh level. We are then about 400 feet under-ground—a sufficient depth to bury St. Paul's. We take the level to our right, and pursue it until we reach the men at their work. There is a tram-road along the level, for running the stuff to the shaft, so that it can be raised to the surface. In some of the smaller mines this is done by boys with wheel-barrows, which, with the exception of working the ventilating machine, is the only purpose to which boys are put below. We proceed about one hundred feet in a horizontal course, when we come upon the miners. When they take a pitch (that is, a belt of the metal lode), they generally work it up, not down; that is to say, the men working from the seventh level, work up towards the sixth (from the surface of the ground), not down towards the eighth. Their object is to follow the lode, and extract the ore from it, disturbing as little of the non-metallic ground as possible. When the lode is wide enough, they work nothing but the lode, leaving the matter on either side untouched. A miner will thus work in a lode only eighteen inches wide; but if it be narrower than that, he has to clear away some of the 'country'—which is removing a sufficient quantity of the granite, slate, stone, or other substances that may envelop the lode, to enable him to follow it. Those upon whom we have come are engaged in this work. They are preparing to clear away the granite by blasting it. The hole for the powder is made with a 'borer,' held by one, whilst the other strikes it with a large sledge hammer. The latter is in a state of profuse perspiration, whilst the other is shivering with cold. They are both completely wet; as, indeed, we are ourselves. The man with the hammer has nothing on but his flannel trousers. The beatings of his heart, which are quick and strong, strike painfully on the ear. He seems to be galloping through life: and so he is; for the miner is generally but a short liver. We leave this part of the level, and take that on the other side of the shaft, which we follow for a considerable distance, until we come to a hole, through which we have to crawl on all-fours. We then find ourselves at the bottom of a winze (a cutting extending from one level to another, and somewhat resembling a shaft) which we pass, and pursue the level. The men have worked up for a considerable distance, making stages for themselves as they rise into the lode. The ore is carefully separated from the stuff (earth, &c.), and is carried over the tramway to the shaft."

Such is a graphic description of a descent into a copper or tin mine, as experienced in Cornwall. It somewhat contrasts with that we have given at p. 9, *ante*, in reference to a visit to a coal mine; and, in one sense, it is a relief to know that no danger can exist in an accidental explosion of *fire-damp*, from which, of course, metal mines, apart from coal, are entirely free. Some of the mines in Cornwall have a depth of upwards of 300 fathoms, or 1,800 feet; and the descent and ascent by the miner is made by ladders, two hours being spent in this double duty daily. The lower we descend in the earth, the higher, as a rule, does the temperature rise; and, at the depth we have mentioned, the heat is so great, arising from a variety of causes, that the men work in a state of nudity, or nearly so. We may illustrate the method of working metal mines of all classes by some remarks, and the accompanying illustrations. In Fig. 80 we first notice a house, in which is a steam-engine on the surface of the ground, by which the water is pumped from the mine, and the ore raised to

the surface. The vertical black line represents a perpendicular shaft, to the left of which is an adit (already described at p. 42, *ante*) ; and the

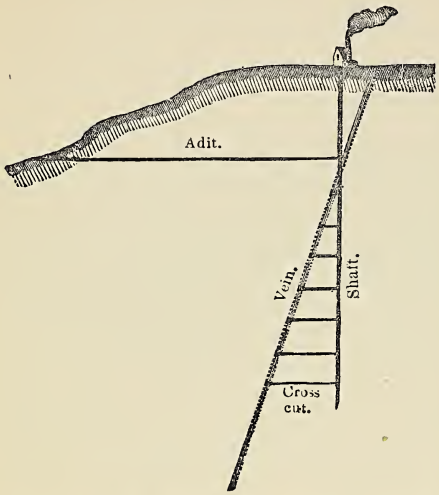


Fig. 80.—Cross Section, showing the progress of a shaft after cutting the vein.

entrance to which is illustrated, as often constructed, by Fig. 78, on the same page. The vein is supposed to run at an angle with the horizon ; in this case considerably exaggerated beyond the usual angle with the horizon. The horizontal short lines between the intersection of the vein and the shaft, represent successive levels, which have been alluded to in the description of the descent into a Cornish mine, just given.

In some mines horizontal galleries are cut, as represented in Fig. 81, which is a convenient

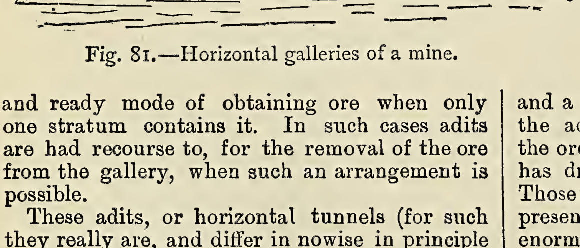


Fig. 81.—Horizontal galleries of a mine.

and ready mode of obtaining ore when only one stratum contains it. In such cases adits are had recourse to, for the removal of the ore from the gallery, when such an arrangement is possible.

These adits, or horizontal tunnels (for such they really are, and differ in nowise in principle from a railway tunnel, except in size, and the careful construction of the latter, because it is so subject to constant vibration from the passage of the trains through it), are often of very great extent. In the north of England, they at times, exceed four miles in length ; and in Cornwall there is one whose whole length exceeds thirty miles. Of course, the shaft and adit methods are respectively chosen according to the known or supposed position of the lode, in respect both to direction and dip; and in commencing a mine for copper or tin, this becomes frequently a matter of great uncertainty, at times causing the loss of a large amount of capital.

The position, direction, and dip of metal veins are by no means so regular as those we have described and illustrated in reference to coal-mining, at p. 6, *ante*, *et. seq.*, Figs. 58, 59, 60 and 61. There we noticed a general tendency to a horizontal position ; or if not, the strata, at whatever angle they may be inclined to the horizon, still preserve their continuity usually in a direct line. Not so with metallic veins of ordinary metals ; for we can only consider them as filling up narrow cavities, as a rule. Much depends on the metal itself ; and next to coal, ironstone or ore is most regularly distributed in the mine, much resembling that material in its position, dip, &c. From this distinctive character we may divide the deposits of metals into at least four classes, such as *veins* (of copper and tin), *beds* (of iron ore), *masses* (frequently occurring in respect to lead), and *fragmentary deposits*, common in tin and many other metals. Veins of tin, lead, zinc, silver, gold, and copper, are of common occurrence ; and, indeed, in the original condition, or perhaps position, of these metals in the earth, as ore or native, are characteristic. The two following illustrations, Figs. 82 and 83 will give some idea of the distribution of veins of copper traversing rock ; the letters *a b* illustrating two kinds of rock, through which the vein is supposed to penetrate.

In regard to beds, we may illustrate such condition of minerals by referring to Figs. 58, 59, 60, and 61, p. 6, *ante*, which illustrate the coal-beds; and, as just stated, such is a common condition of the iron ore, especially as found in the black band of Scotland. Pipe-veins, or masses, are usually confined to lead and copper, but occasionally iron. In respect to fragmentary deposits, we may include the nuggets of gold found far from their original source, as in Australia, Columbia, California, &c. ; and, in England, stream tin has taken its position far from its original source, from the same cause. In both of these, and in all similar cases, the vein, bed, or mine has been broken up by some mechanical cause, and a current of water has either washed away the adjacent earth, leaving isolated masses of the ore ; or, perhaps, by its overpowering force, has driven such masses along in the current. Those unacquainted with phenomena that geology presents us, can scarcely have any idea of the enormous force that a stream of water may thus generate. We may instance two occurrences of recent years, however, to illustrate it ; and both will be familiar to many of our readers. Some years ago, the Crinan canal, in the north-west of Scotland, burst its banks, and masses of rock,

&c., several tons in weight, were removed to a great distance by the force of the current. Still more recent was the bursting of the reservoir of the Sheffield water-works, by which houses, factories, bridges, and other strong buildings, were completely swept away by the current. On the continent, floods frequently occasion even more disastrous results, owing to the sudden rise of rivers. In 1879, a large city of Austria was completely swept away by this cause, leaving some hundreds of people homeless. Similarly we account by the action of water-forces, for the presence of fragmentary deposits of metallic ores, far from the vein, bed, &c., in which they first existed.

The faults in a vein much resemble, in general character, those already noticed in respect to the same occurrences in coal mines, described at p. 6, *ante*. But the chance of losing a metallic vein is much greater than that incurred in respect to a coal seam; not alone arising from the difference of the thickness, but also from other causes incidental to the particular metallic ore so affected. This will be still further apparent when we state that copper, as a rule, occurs in much earlier (or older) rocks than the carboniferous series, that afford the coal measures, and therefore they must first be affected by disturbing causes. Our copper and tin mines, for example, of Cornwall, belong to a lower strata than the carboniferous series, which, as a rule, generally superimpose them. Of course it requires some acquaintance with the geological character of our country to understand this; and no information can be conveyed by writing adequate to a full description of the question. Those however, who have visited, in succession, Devonshire and Cornwall, Derbyshire, some parts of Yorkshire, and crossing through Northumberland to Carlisle, thence by the Caledonian Railway to Glasgow, will start first from the lower strata of old red sandstone, or the Devonian series; arriving in Derbyshire at the carboniferous series, continuous, more or less, through the route we have named, until Glasgow is reached. Travelling northwestward, in Scotland, the limestone connected with the carboniferous series, iron mines, &c., is passed over; but north-easterly from that city to Inverness, a similar class of rocks is met with as is found in Devonshire and Cornwall. Now, throughout these various strata, lead is chiefly found amongst the limestone series, as in Derbyshire and Yorkshire, with the southern portion of Lanarkshire (Leadhills), in Scotland; whilst copper is discovered mostly in slates, schists, and rocks of porphyritic character, or lower in position, and earlier in formation, geologically, than the limestones. A kind of immense basin or series of basins, may be imagined, in which limestone, coal, and iron take the uppermost position; lead next, lower; and copper, with tin, as the lowest, from the *geological* surface of the earth, of all that we have mentioned.

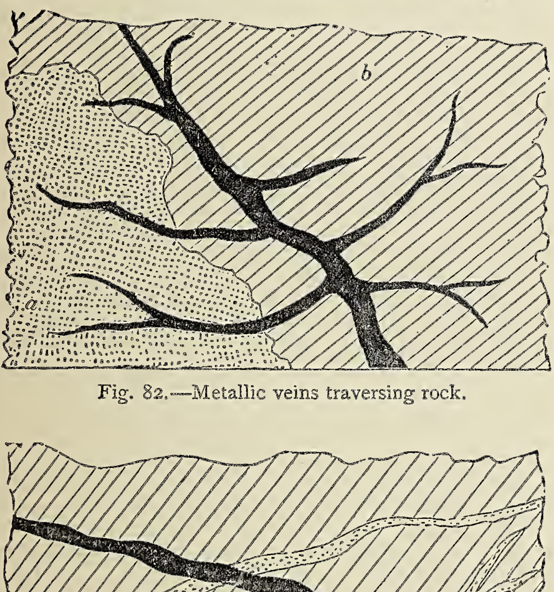


Fig. 82.—Metallic veins traversing rock.

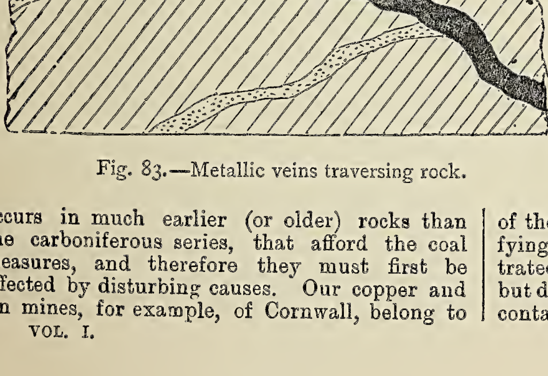


Fig. 83.—Metallic veins traversing rock.

It is evident, therefore, that the lowest of the strata must be most liable to disturbance or dislocation; and such is found to be verified as a fact, in respect to the faults of veins of the last-named metals. They are nearest to, and, in fact, are found in, what are called metamorphic rocks, that are, in England, especially situated in Devonshire and Cornwall.

So far for the geological principles involved in the question. We must recur to its practical bearings.

In Fig. 60, page 6, *ante*, will be found an illustration of the nature of a fault in a coal mine, in which the elevation or depression of one portion of the bed and strata, accompanied with the dislocation of the seams of coal, is represented by the deep black lines. In the following cut, Fig. 84, a representation is given of an analogous fault in a mineral vein, together with the intersection of two veins. A careful comparison of cut (Fig. 60), with the present, will show that the mechanical result is precisely the same, although, in the case of the metallic veins, there are other and modifying circumstances. One of the veins illustrated in Fig. 84 has not only been intersected, but driven out of its original position. Fissures containing mineral deposits, as at *j j*, frequently

occur; but are of little or no value to the miner. It will be noticed that the strata on the right side of the cut have been raised above those on the left; or the occurrence may be explained on the reverse supposition—namely, that the left-hand strata have been depressed. These dislocations, disturbances, elevations, or depressions, are the chief causes of the uncertainty of mining; which will be better understood if our readers will imagine, for a moment, the removal of either vein No. 1 or 2 from the cut, and leaving but one remaining. Supposing, for example, that No. 1 had been worked to that point where No. 2 touches it; in the absence of No. 2, the vein or lode, would instantly cease, for the lower part of vein No. 1 has, by the disturbing causes, been far removed from its old position. It hence has frequently happened that the miner works for a long time in a rich vein or lode: but suddenly arriving at a point where the dislocation has been effected, his hopes are suddenly cut off; and, in many cases, it is impossible for a long time, if at all, to discover where the vein exists. An eminent example of this is related in Forster's *Section of Strata*, in respect to a lead mine at Llangunog, in Wales. The vein of galena (sulphide of lead, or lead pyrites) had a width of no less than five yards. It was so rich and pure in quality, that "the ore was poured out of the kebbles at the shaft-head into the waggons, and carried directly to the smelting-house, without being touched by the washers and dressers of ore; besides several feet upon the sides of the vein, which was mixed with spar and other stony matter, and went through the hands of the washers." But, at last, this magnificent vein was cut off by a schist fault, and was never afterwards recovered.

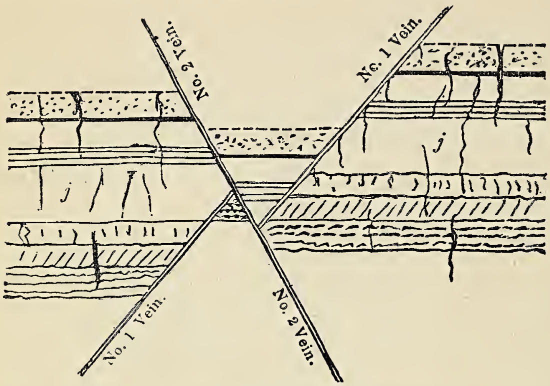


Fig. 84.—Metallic veins intersecting strata.

The class of fault to which we here draw attention is called a slip-vein. "They traverse all the strata, but they do so unequally; that is, the interval between the walls is very apt to vary in crossing different rocks; and the nature of the vein for ore is greatly affected by the nature of the strata. They contain ore often distributed in threads or strings of various thickness, with much spar or other mineral matter (see *j j* in the preceding cut); but the actual space is often filled up with clay.

"Obeying the law of faults, already spoken of in reference to the coal measures (see our remarks on this subject, at p. 6, *ante*), there are certain technical rules for miners in slip-veins, derived from observation; and they are extremely useful. Amongst these may be mentioned the fact, that if the vein traverse several strata, it will be found most regular in the thickest of them. It is also the case, that the ore in such veins is extremely irregular, following no law that can be traced to have regard to the nature, magnitude, regularity, extent, or other conditions of the vein.

"It is regarded as a bad sign in a working to find the vein to diverge into two strings; and, on the other hand, a junction of two or more strings, or veins, is looked on as favourable. Veins that cross the prevailing systems (see preceding cut) have rarely been found so productive of metallic ores as the others, except at the place of crossing, where they are usually rich."—(*Ansted.*)

It has been previously stated, that, as a rule, the thickness of metallic veins or lodes is generally less than that of the largest seam of coal. But many exceptions to this arise. At Fahlun, in Sweden, for example, there is a mine in which the minerals are distributed to the extent of several hundred yards wide; and, in Piedmont, iron ore has been found not less than 350 yards thick. In some parts of the United States the lodes are of enormous dimensions; and, in the case of copper, so pure that we have seen specimens of the native metal not containing so much as 5 per cent. of earthy matter (chiefly quartz), that required no smelting, but simply melting, and casting into ingots, for commercial purposes. Such instances may also be met with in Australia; but they are exceedingly rare, when considered in relation to the general distribution of copper, or other metals, throughout the upper crust of the earth. Gold is always found in the native state; and is very generally diffused in this condition.

In all metallic veins many other matters exist, such as quartz, aragonite and other carbonates of lime: the fluates of lime, so abundant in this country, as Derbyshire spar; sulphates of lime, barytes, and other minerals—all of which are of course, causes of expense in their removal, and useless to the miners. The great presence of these occasionally render a vein not worth working—instances of which may, almost invariably, be found in all mining countries. The presence of clay is of frequent occurrence, much deteriorating the value of a lode: and such a condition is technically termed, in Cornwall, a *Flookan.* In numerous cases, iron, in various conditions, is present, especially as the sulphide, or iron pyrites. When a vein has a ferruginous appearance, arising from the pre-

sence of infiltrated oxide of iron (and termed a *Gossan* in Cornwall), it is considered as a favourable symptom, and leading to a good vein. Indeed, the practical miner, in respect to his occupation, is the parallel of the shepherd or sailor, in their predictions of weather. Neither knows much of the science of the question; but long experience, and accurate observation, lead to so much practical knowledge as rarely to result in erroneous conclusions.

At times, veins or lodes are intersected by igneous matter, that either elevates them or cuts off their continuity. Such walls, or bars, are analogous to the dykes of the coal-field already described, and proceed from the same causes. Their technical name, in relation to metal-mining in Cornwall, is *Elvans.*

We have thus described most of the circumstances that accompany the existence of ore in veins or lodes; at least so far as they generally affect the subject of metal-mining. When we enter into an examination of the methods individually adopted for each metallic ore, the modes of dressing, smelting, &c., &c., we shall notice several other circumstances that are of a more special character, and referable chiefly to the metal under examination. The major portion of what we have stated in the preceding pages, is capable, more or less, of universal application.

Before closing a general view of metal mining, attention may be drawn to an invention which has lately come into much use, in the earlier stages of shaft sinking, and other similar objects. It is the *Pulsometer.* This is a simple and cheap contrivance, whereby water and most other liquids, whether clear or turbid may be raised by the force of steam, and delivered in a constant stream to a height of from fifty to eighty feet, without the intervention of a pumping engine, and it is especially adapted for sinking wells, making foundations, &c. It will be found useful to manufacturers and mine owners, wherever a pump is required that needs a minimum of attention. The simplicity of the pulsometer will be understood from a description of its parts, which are an outer casing divided into two chambers, one ball valve controlling the admission of steam at each pulsation, and the usual suction and delivery valves common to all reciprocating pumps. Fig. 85, represents a section of the Pulsometer.

The two chambers are contained in one casting, and are gradually tapered upwards till they unite in a neck; this neck contains the steam ball valve, which, by its oscillation, admits steam alternately to each chamber. The chambers are connected at the bottom by a breecher piece, which leads to the suction pipe, and carries two suction valves. On the side of one chamber is attached a discharge box, containing the delivery valves, and leading to the discharge pipe. Doors are provided for easy access to all the valves. The pumps being filled with water, steam is admitted at the top, and passes down whichever side of the steam neck is left open by the position of the steam ball, and presses on the small surface of water exposed to it, depressing it without any agitation, and consequently with very slight condensation, and thus driving it through the delivering valves into the rising mains. The moment that the level of the water is as low as the horizontal orifice leading to the discharge chamber, the steam blows through with a certain amount of violence, the surface of the water becomes agitated, an instantaneous

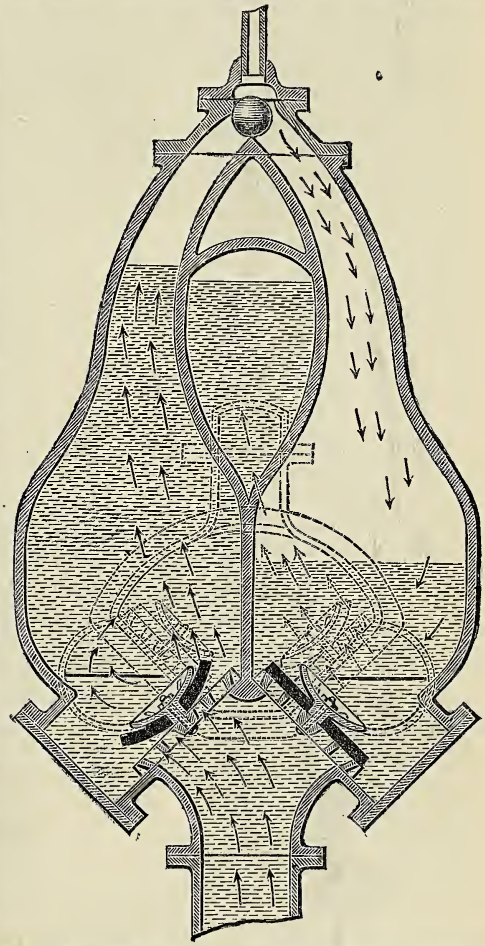


Fig. 85.—The Pulsometer in Section, showing direction of steam and water current.

condensation takes place, a vacuum is formed in the chamber, and the steam ball is pulled over into the seat opposite to that which it had occupied during the operation just described. The same action then takes place in the second chamber, and by this means a continuous stream is discharged. As the valves are the only moving parts, they and their seats are the only parts ever requiring to be renewed. These renewals are only necessary at very long intervals, and can be effected in a very short space of time, and at a comparatively insignificant cost. The pulsometer is capable of pumping water or other liquids containing from 15 to 20 per cent. of muddy, pulpy, or gritty substances.

Fig. 86, shows a pulsometer engaged in sinking work. It will be observed that it is merely suspended in chains, no further fixing being

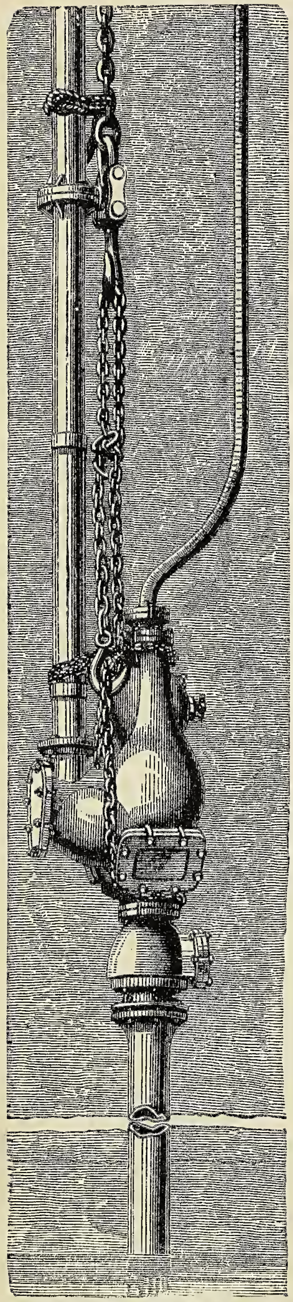


Fig. 86.—The Pulsometer.

required, and as steam is supplied through a flexible pipe, the pump can be easily lowered as the operation of sinking advances. These pumps are well suited for draining quarries and mines, as they occupy a small space and require little attention. In fact they may be kept in work for weeks together, giving no trouble of any kind.

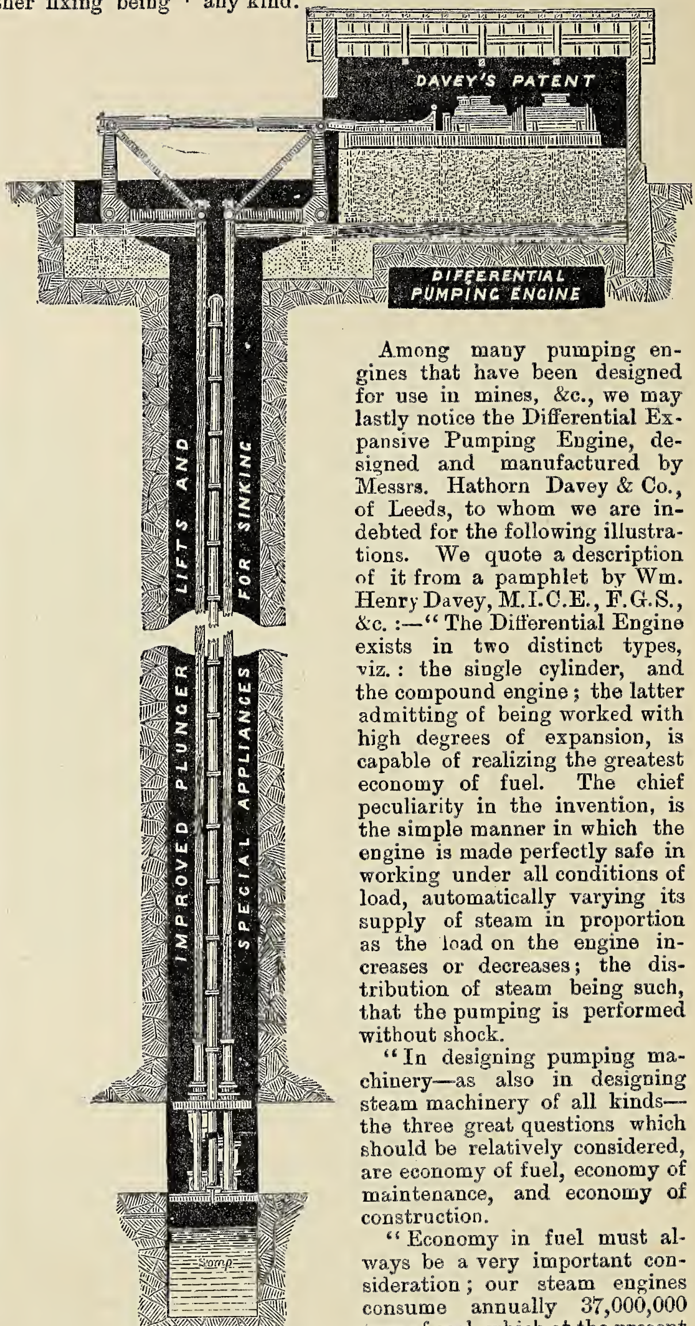


Fig. 87.—Differential Pumping Engine.

Among many pumping engines that have been designed for use in mines, &c., we may lastly notice the Differential Expansive Pumping Engine, designed and manufactured by Messrs. Hathorn Davey & Co., of Leeds, to whom we are indebted for the following illustrations. We quote a description of it from a pamphlet by Wm. Henry Davey, M.I.C.E., F.G.S., &c. :—"The Differential Engine exists in two distinct types, viz. : the single cylinder, and the compound engine; the latter admitting of being worked with high degrees of expansion, is capable of realizing the greatest economy of fuel. The chief peculiarity in the invention, is the simple manner in which the engine is made perfectly safe in working under all conditions of load, automatically varying its supply of steam in proportion as the load on the engine increases or decreases; the distribution of steam being such, that the pumping is performed without shock.

"In designing pumping machinery—as also in designing steam machinery of all kinds—the three great questions which should be relatively considered, are economy of fuel, economy of maintenance, and economy of construction.

"Economy in fuel must always be a very important consideration; our steam engines consume annually 37,000,000 tons of coal, which at the present moment may perhaps be reckoned at an average of 15*s.* per ton, representing over £27,000,000 sterling; an economy of 25 per cent. would therefore effect a saving of nearly £7,000,000 annually.

"With colliery pumping engines it is not unusual to find a consumption of from 12 to 14 lb. of coal per horse-power per hour. A good compound engine will work with less than a quarter of that amount of fuel. The savings to be effected on 400 horse-power of actual work, by the substitution of a compound engine for a non-expansive engine, would be, at the lowest estimate, thirty-six tons in twenty-four hours; which, taken at 5*s.* a ton at the pit's mouth, would amount to the sum of £2,700 per annum.

As a question of first cost only the necessary boiler power must be taken into account, and it very often occurs that the total cost of the engine and boilers is in favour of the most costly and most economical engine.

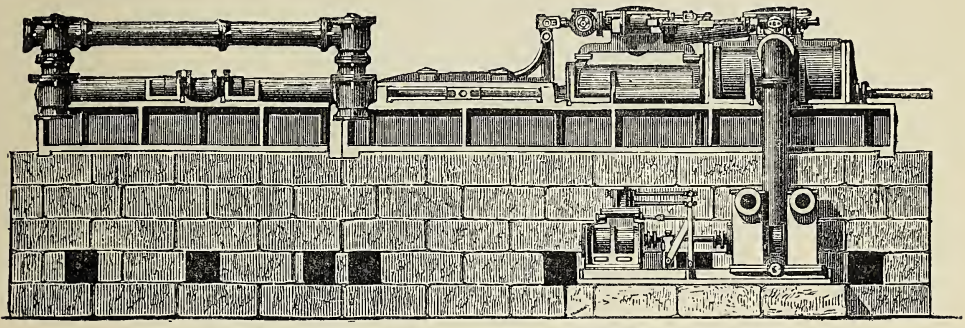


Fig. 88.—Differential Pumping Engine, applied under ground.

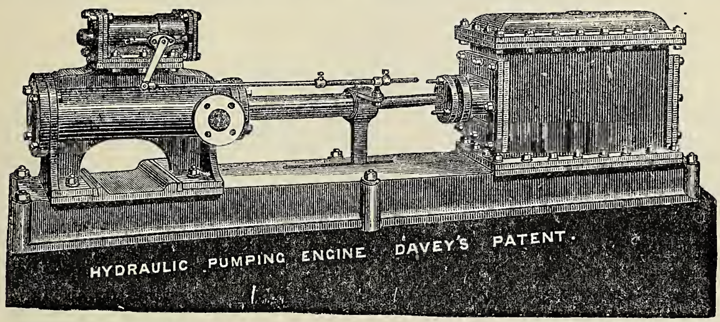


Fig. 89.—Hydraulic Pumping Engine.

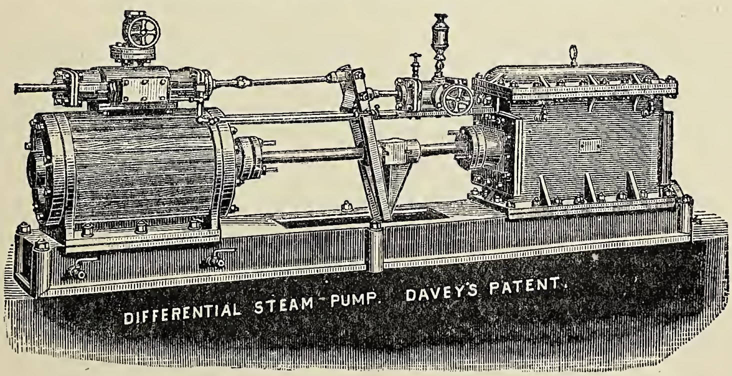


Fig. 90.—Differential Steam Pump.

"The leading principle of economy is expansion, and the engine which will work with the greatest amount of expansion is, *cœteris paribus*, the most economical. There are, however, certain conditions necessary to economical working. The resistance to be overcome in pumping, is almost constant, and the force applied to overcome that resistance by the expansion of steam, varies. A mean then is required whereby work may be stored up, whilst the piston is moving through

the beginning of the stroke, and given out again whilst it is further moving towards the end of the stroke. That function is performed in the Cornish engine by the inertia and momentum of the pit work beam column, and other inert matter; and in the rotative engine, by that of the fly-wheel. It is evident that when a high degree of expansion is employed in a single cylinder an enormous strain (above the resistance of the pump) is put on the engine at the commencement of the stroke; and also that the maximum piston speed must be very great.

"These are two of the most serious difficulties surmounted by the Compound Differential Engine. A range of expansion which would produce a variation of strain of six to one in a Cornish engine, would only give two and a half to one in the compound engine; that is to say, the strains are nearly three times as great in the Cornish engine.

The importance of thus reducing the strains on the machinery is obvious. The engine may be made lighter, with greater security against breakages. The foundations become cheaper, whilst the speed of the engine is rendered more uniform.

In the compound Differential Engine, not only are the strains and maximum speeds reduced for a given ratio of expansion, but the *effective* piston speed is increased, because the engine is double instead of single acting.

"Next in importance to economy of fuel in pumping engines—or frequently of more importance—are safety in working, and immunity from stoppages. The distribution of steam should be effected in such a way, as to cause no shock or slip in the pumps; and in the event of a sudden loss of load, the engine should be safe; in short, the engine should be self-governing under extreme variations of resistance. To effect this, the Differential Valve Gear was designed, which admits steam to the engine in proportion to the resistance to be overcome; and in the case of a sudden total loss of load, reverses the steam to catch the piston. The distribution of steam is effected by coupling the motion of the engine with that of a piston having a uniform velocity. The engine is made to cut off steam by its motion, whilst the uniformly moving subsidiary piston is employed in admitting it. As long as the resistance to the engine is sufficient to prevent its motion becoming relatively equal to that of the subsidiary piston, steam is admitted up to the fixed point of cut off; but should a loss of resistance, or a superior pressure of steam, cause the engine to acquire a speed relatively greater than the speed of the subsidiary piston, then the motion of the steam valve would be reversed earlier, and the supply of steam would be adjusted to the altered conditions."

Such are the general principles on which Messrs. Hathorn Davey & Co.'s Differential Engine is constructed, with a statement of some of its advantanges. Fig. 87 represents a section of one of their pumps, especially adapted for sinking and worked above ground. Fig. 88 represents a similar engine, as applied underground. Fig. 89 represents a hydraulic pumping engine. Fig. 90 illustrates a Differential Steam Pump of a different type. In Fig. 91, a winding machinery for colliery and general mining purposes, by the same makers, is represented.

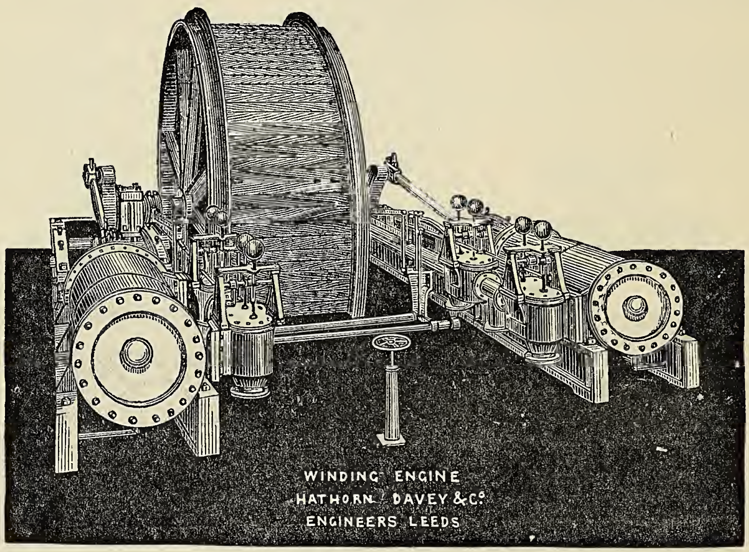


Fig. 91.—Winding Machine for Mines.

John Rennie

CHAPTER III.

IRON SMELTING, MANUFACTURES, ETC.

IT will be unnecessary for us again to urge on our readers the importance of the iron manufacture to this country, as we have already, in our previous pages, stated so much to that effect. It will be sufficient for us therefore to remark, that as it ranks first in commercial and national value, in respect to any of our metal productions, this fact is an ample reason for its taking the first place for consideration in metallurgy, so far as our work is concerned.

Iron is indeed to us a "precious metal," much more so than those to which this appellation is commonly given. The well-being of our island has depended on the existence of her iron-mines, to a degree, which it is exceedingly difficult to estimate properly: when two such bountiful gifts as coal and iron are compared, one is almost inclined to admit that either is less important than the other; but when both come together, as they do in England and Scotland, we have much to be grateful for. It has been a subject of remark, as a happy thing for this country, that the iron ore of Great Britain occurs not only in the vicinity of, but actually associated with the coal necessary to separate the metal from the impurities of the ore. In Sweden, and most other countries, where iron mines exist, the ore is refined by means of wood, as already stated. But no space in our island could afford sufficient wood for that purpose. Consequently without coal, in place of being great exporters of manufactured iron to distant nations, we must have depended on other countries for this metal, to the vast detriment of many of our manufactures, which mainly owe their improvement and extension to the abundance and consequent cheapness of iron.

The iron districts of Great Britain are widely extended; and therefore cannot be considered as confined to any special strata. Indeed, it is so universally distributed, even from the mine to the blood of our bodies, that we can rarely find it absent, in any part of our island, in the animal, vegetable, or mineral kingdoms. The clay, for example, so common in many parts of these islands, most of our rocks (omitting chalk, sand, mountain limestone), most plants, and all vertebrated animals—or, at all events, the warm-blooded tribe—contain iron in some form, but chiefly as an oxide. In respect to metallurgy, however, we are, of course, restricted to the mineral kingdom; and, consequently, to the beds or other deposits of sufficient richness to make them worth working.

The metal and its ore are found in various chemical conditions. Rarely, from its great attraction for oxygen, is it found native; air and moisture speedily reducing it to the condition of an oxide—a common form of its ore. In its native condition, as a metal of this globe, it is characterised by an absence of nickel, that always accompanies iron of meteoric origin. This is a most remarkable fact, *per se*; but when we call to mind that the two metals are so closely united by chemical, physical, and mechanical ties, the significance becomes exalted. Native iron has been found in the United States, Brazil, some parts of France, and other portions of Europe. Its specific gravity, in this condition, varies from 7·09 to 7·80; water = 1·00. As meteoric iron, ærolite, meteorite, &c., it is found associated with metallic nickel, cobalt, and other metals. In the British Museum are numerous specimens of meteoric iron, gathered from various parts of the globe, in almost all known parts of which it has been discovered. Many curious speculations have been indulged in regard to the meteoric source of iron, the moon coming into full consideration as supplying it, although no satisfactory reason has yet been afforded for such a suggestion. The more probable cause is the falling of some portion of the meteoric bodies that occasionally visit terrestrial regions; and of which so brilliant, and almost unparalleled, a display was witnessed in November, 1866. In the north of North America meteoric iron seems abundant, and forms the material for knife-making amongst the Esquimaux.

But native iron is of far too rare occurrence to be of any value as a source of the metal for commercial purposes. Our chief supplies of the metal in Great Britain, are drawn from the oxides, sulphides, and carbonates; which are variously distributed, and often in great abundance, locally. Hematite is one of the most important of our iron ores. In England, varieties, red and brown, are found near Whitehaven and Ulverstone, the Forest of Dean, Devonshire, Cornwall, and Wales. The usual situation of this variety of iron ore is in beds and veins of the older rocks; but, at Whitehaven, it appears as having been transferred from that position to newer strata, possibly by the action of water. "The brown hematites deserve special attention. They are found associated, in very large masses, with the lead vein of the district (Weardale and Alston Moor); and, occasionally, they occur in distinct and regular beds. They contain from 20 to 40 per cent. of iron. Sometimes

they exist as riders to the vein; sometimes they form its entire mass; and in this case they occasionally attain a thickness of twenty, thirty, and even fifty yards. Their employment for iron-making purposes is comparatively recent; but the supply of ore which they can furnish is almost unlimited."

The black band, one of the chief sources of iron, is found in Wales and Scotland; the valley of the Clyde, or rather nearly the whole central portion of Scotland, from Ayrshire to the German Ocean, mostly abounding with this valuable ore, alternating with beds of coal, and abundantly supplied with limestone as a flux. The neighbourhood of Coatbridge, Gartsherrie, where are Messrs. Baird's works, one of the most extensive in the kingdom; Wishaw or Coltness, Glasgow, and various parts of the adjacent country, especially Lanarkshire, are all the scenes of extensive smelting-works, in which an immense quantity of Scotch pig-iron is produced from the black band. The ore is readily obtained and smelted, because all the conditions essential to a successful mode of producing the metal are present; and hence the entire neighbourhood is one unceasing scene of activity day and night, the cloud of smoke, or pillar of fire, being a constant indication of the processes of smelting incessantly carried on. Returning to England, near the eastern coast of the counties of Durham and Yorkshire, and within but a few years, a new and most valuable source of iron ore, the carbonate of the metal, has been discovered. We refer to the Cleveland district, formerly quite neglected in respect to its value, but now supplying a large per-centage. In this district about 2,500,000 tons of pig iron were produced in 1880. About the earliest of these mines that were worked were those of Easton, in 1851. From Middlesborough to Guisborough the beds are about six feet thick; but are nearly fifteen feet near Easton. The discovery of this valuable source of iron has completely changed the aspect of the entire country, which, from being comparatively unknown, is now every way occupied with furnaces, in which smelting operations are vigorously carried on. The carbonate of the metal is mixed with a little clay and silicious matter, the proportion of iron being about 30 per cent.—an excellent average, when compared with many other districts in this country. Other parts of Yorkshire, Durham, and also Northumberland, yield more limited supplies; and chiefly white carbonates, or hematites. The carbonates of the Cleveland district belong to the lias formation.

Proceeding in a south-westerly direction, we enter the North Staffordshire field, in which an immense quantity of ironstone is found; mostly smelted, however, in South Staffordshire, or Wales. Some of the beds run from four to ten feet thick. The iron is either of the black band or carbonate; South Staffordshire, however, is most noted for both the quality and quantity of its production. Coal and ironstone greatly abound; hence smelting operations are most extensively carried on, as is also the purification of the cast-iron by puddling, &c., and the manufacture of wrought-iron. We need scarcely remind our readers that Dudley, Walsall, Wolverhampton, and Birmingham, may all be included in this district; and the names of those towns will be a sufficient assurance of the importance of iron production and manufacture carried on.

Still further west, we enter the Wales fields, where black band in South Wales, and other ores, are of the greatest importance in reference to the production of iron. Abundance of coal also exists (see *ante*, pp. 3, 4, &c.); and hence this district ranks as one of the most valuable in our islands. Copper smelting is largely carried on, from the abundance of fuel, in the southern portions.

Shropshire, Lancashire, Cumberland (West), all produce iron; and we may especially name Whitehaven, Ulverston, and the Furness districts, as producing much ore, shipped to various southern districts (Staffordshire, Wales, &c.), for smelting. With these we may include other sources of iron where fuel is not found for smelting purposes, and whence, therefore, the ore is exported for that object. Of these, especially, is the Forest of Dean, in Gloucestershire. Here "the ores are carboniferous, lying beneath the coal measures; but there is also a bed worked locally in the millstone grit. The limestone ore occupies a regular position in the measures, assuming rather the character of a series of chambers, than a regular bed. These chambers are sometimes of great extent, and contain many thousand tons of ore, which is generally very cheaply raised; no timbering, or other support for the roof, being required. The supply of ore is almost unlimited; and the iron made from it is celebrated for the manufacture of the best tin plate, and always bears a high price. It is raised extensively for shipment to the iron-works of South Wales (for smelting). It was worked at a very ancient date, either by the Romans or Britons, as is evident from the remains of old workings along the outcrop of the ore-bed. The ore averages from 30 to 40 per cent. of of iron."—*(Ansted.)*

Amongst other miscellaneous sources of ore are the hydrated oxides of Northamptonshire, Wiltshire, Oxfordshire, Lincolnshire, &c.; and of these, the Northamptonshire oolites are very abundant, and generally rich. There are also the spathose ores of the Breda Hills and Exmoor. In some parts of North Wales are pisolitic (or peastone) ores, found in Anglesea, Tremadoc, Pwllheli, Carnarvon, and shipped to South Wales for smelting. In Sussex, amongst the greensand, iron ores are abundant; and recently, a new, and apparently very valuable source, has been discovered in Cornwall.

Such is a brief description of the leading sources of iron ore in this country; and it will be seen that not only is the variety great, but so is the geographical position, extending from the carboniferous or mountain limestone of Cumberland, Lancashire, Durham, Yorkshire, Gloucestershire, Somersetshire, Wales, Derbyshire, &c., or the older rocks of Devon and Cornwall, that frequently contain veins of black hematite; the new red sandstone, affording

conglomerates of hematite, up to the oolites of Northamptonshire, the greensand of Sussex, and the lias of Yorkshire. At one time many of these were all but valueless, because of an entire absence of fuel, or the enormous expense that would have been required to transport it to such localities. The expansion of our railway system, however, is gradually bringing again into use beds that have laid unnoticed for centuries; but which, in early times, were worked by aid of charcoal, when wood was very much more abundant in our islands than at the present day. We thus perceive how one invention may benefit another. At a previous page, it was pointed out how the application of the steam-engine to mining had so greatly facilitated such operations, especially in respect to pumping-up water to drain pits, and to raise the material afforded by them (see *ante*, p. xv). We now see a still further advantage of the invention of the steam-engine, in the form of the locomotive, creating branches of industry, and means of employment in districts where our most valuable native metal abounds; but that, until this development of the railway system, were practically of no value. No improvement in any branch of science, or its applications, can be made without at once, directly or indirectly, conferring benefits on others.

In respect to foreign countries, Sweden may, perhaps, take the first place in respect to the quality, if not the quantity produced. Its metal is always highly esteemed in the market for its great purity, which makes it of much value for many purposes in the manufacture of various articles in iron and steel. The productions of France and Belgium are extensive; and the latter has been able, of recent years, to compete with us in iron manufactures. Spain is rich in iron and other ores, many cropping to the surface; and, indeed, the circumstances of its mineral and fuel distribution are such, that were it not for the political condition of that country, and the absence of anything like commercial enterprise, it might soon take a place amongst the foremost of metal-producing nations. Italy has numerous sources of iron ore, some of an exceedingly rich nature; but the total production of metal is miserably small, the greater portion of the valuable mines being unworked—a circumstance arising, like the condition of Spain, from the utter want of energy of the people, and their uncertain political state. Russia produces very excellent iron. In respect to Germany, Austria is very rich in most metallic ores, which are generally distributed, but especially in Styria, Carinthia, Hungary, and Bohemia. Indeed, after carefully examining the specimens of metallic ores shown at recent Exhibitions, we were puzzled to understand how an energetic race like the inhabitants of that country, could remain satisfied with their low pecuniary and financial position amongst European nations generally, considering the enormous mineral riches they possess, especially in regard to iron. Its ores chiefly consist of carbonates and oxides. Prussia, and other countries of the Zollverein, are generally productive of iron.

Africa and Asia we may pass over by simply noticing, that, in various parts, metals are enormously abundant, but little worked. In America the production of iron is very great, and, of course, it, and all other metals, are plentiful. Indeed, the American continent, from the Polar regions to the south of Brazil, or possibly even much further south, abounds in minerals to an extent that would supply iron, copper, lead, gold, &c., to an unlimited extent, and generally of great purity.

There are several other ores of iron, generally diffused throughout the world, but of less common occurrence than those we have named; amongst which are the following:—*Magnetite*, *magnetic iron ore*, *octahedral iron ore*, or *oxy-ludated iron*—names synonymously used by mineralogists—is found in many parts of Europe, as Norway, Sweden, and Lapland; the Ural chain of mountains, on the east of European Russia; Corsica and Elba, on the Mediterranean; Spain; and in many parts of the United States, as New York, New Jersey; also in Mexico, Brazil, &c. In England it occurs in Cornwall, and in Ireland in the Wicklow range of hills. It is highly magnetic; in fact, as obtained, also, from Siberia and the Hartz mountains, in Germany, it forms the best kind of loadstone, or natural magnet. It is an exceedingly good ore, especially for the manufacture of steel; and is a mixed oxide of iron, containing the proto and sesquioxides. It is one of the most important ores, in the manufacture of iron, employed by the United States. *Gothite* and *Limnite*, both hydrated oxides of iron, have each received also the name of brown hematite; the chief and most abundant variety of which has been already described as one of the most important iron ores of our islands. *Turgite* is also an hydrated oxide, occurring, occasionally, in the Ural and Altai chains. *Pyrite*, or *iron pyrites*, a sulphide of iron—that is, the metal united with sulphur—is largely distributed in most geological strata, at least of recent formation. It is especially abundant in the Isle of Sheppey, at the mouth of the Thames, the soil of which is disintegrated by its continual decomposition. It is also met with in alum shales; and is, consequently, a source of annoyance to the alum manufacturer, whose produce of that substance is thus often ruined for calico-printing. It is got rid of by him through exposure to the action of air and moisture, by which it becomes oxidised, and converted into sulphate of iron or copperas, largely used for a variety of purposes, as in dyeing, &c. Of late years it has been much used as a source of sulphur, in the manufacture of sulphuric acid, in the manner already mentioned at p. 41, *ante*. It occurs abundantly in some coal formations; and is, occasionally, the source of serious accidents, arising from its oxidation producing so much heat as to ignite the coal (see p. 22, *ante*). *Marcasite*, or *white iron pyrites*, and *pyrrhotine*, or *magnetic iron pyrites*, are also sulphides of the metal. There

are combinations of selenium, arsenic, titanium, &c., with iron, of no importance in relation to its manufacture. In reference to titanium, however, we may observe that it is frequently found in the slag of iron furnaces after cooling. Tungsten unites with iron; the mineral *Wolfram* being a combination of the two metals, or a tungstate of iron. *Chromite*, or a chromate of iron, is a valuable mineral for containing the metal chromium, so much used in the arts of dyeing, painting, &c.; its iron, however, is valueless for any purpose. *Chalybite* is another name for the spathose iron ores already referred to. It is a carbonate of iron; and, as we have already seen, a most valuable ore of the metal occurring in Staffordshire, South Wales, &c., in this country, in the form of clay ironstone. It is also met with in many parts of Austria; and from it the celebrated Styrian steel is manufactured; at least, from the iron first procured from it. The sulphate of iron, or copperas, is frequently met with in old mines; but although, of course, valueless for metallurgical purposes, is largely used in the arts. It has already been referred to as resulting from the decomposition of the sulphide, or iron pyrites. Phosphates of iron are also found; but, as we shall afterwards have more particularly to explain, phosphorus is a common accompaniment of the ore, and a most serious cause of difficulty in the manufacture of iron, because of the injurious effect it exercises on its tenacity. Amongst the native phosphates are *Vivianite*, *Dufrenite*, &c. Manganese occurs in certain ores of iron; and its presence has given rise to a most ingenious application of the fact, in the manufacture of steel, that we shall fully notice hereafter.

Such are some chemical combinations of iron that occur with other bodies, with but few exceptions, useless in metallurgy, yet of various applications in the arts, &c. It will be noticed that iron is thus found under a vast variety of geological and chemical circumstances, verifying the remark that has previously been made in respect to its universal diffusion in nature.

But, to the smelter, it is a matter of the utmost importance to have an ore as free as possible from extraneous matter—a circumstance that can never be completely arrived at, except in the case of native iron. Indeed, the smelting of iron, although comparatively a rough process, as viewed externally to the furnace, is one practically, and in its interior, requiring a careful balance of chemical affinities; in the absence of which, the quality of the metal produced will be greatly affected.

The various minerals that have just been described as not the ordinary sources of iron, are therefore omitted from all consideration in the remarks about to be made, attention being confined solely to the ordinary and most abundant sources as employed in this country.

Ordinarily, any or all of the following substances may be found in iron ore, every one of which, except the iron itself, must be got rid of. The peroxide or protoxide of the metal is generally *the* ore, united (as in the Cleveland district) with carbonic acid; in this case, the protoxide and the acid being combined. There may also be present a minute quantity of the oxides of manganese, a fact at times of much value; lime; alumina and silica, as clay; phosphoric acid, a compound of phosphorus and oxygen, the phosphorus being the bane of the smelter; and water to a very varying amount.

Now the proportions of these substances present in an ore determine its quality. A large amount of some of them would render it valueless; but their proportions, and even their existence, in certain kinds, are subject to the greatest variation. In an analysis by one well known from his connection with mining subjects, and made on the iron ore already described as a hydrated oxide, obtained from the oolite in Northamptonshire (see *ante*, p. 52), the following were the average results of trials on three specimens. It will be noticed that the peroxide of iron and water in combination as the hydrate, and silica as an impurity, are characteristic. The average of each constituent was as follows:—of

Peroxide of iron	49·25
Protoxide of iron	1·05
Protoxide of manganese	1·39
Lime	3·40
Magnesia	0·54
Alumina	6·48
Phosphoric acid	·94
Carbonic acid	4·20
Silica	8·85
Water	23·37
Loss	0·53
	100·00

Whilst quoting the above average results, we must qualify them by stating, that in one specimen the alumina was double in quantity to that found in another; the lime, nine times as much; the quantity of phosphoric acid materially varied, as did that of the carbonic acid. Silica was abundantly present, but varied from 4 to 12 per cent. in two specimens; the water (we presume), chemically combined, ranged from 16 to 27 per cent.

But clay iron ore is that more generally used in this country as the source of iron. As we have already seen, it occurs near beds of coal, shale, and limestone; and hence must naturally be more or less affected chemically by the strata, with which it is in immediate contact. Generally speaking, therefore, we shall find the iron (its oxide) united with a portion of carbonaceous matter, clay (a union of silica and alumina), a portion of lime, and other impurities in smaller proportions. As a rule, we have seen that such ores produce from 30 to 40 per cent. of iron. It is important first to ascertain the nature of the ore, in reference to its richness, and the impurities with which it may be mixed; because, in the operation of smelting, it is absolutely necessary that the latter should be got rid of as completely as possible; hence the use of flux especially, and almost solely, limestone,

that in Scotland and other districts is obtained from rock, adjacent to, and imbedding the iron ore. Its effect, aided by a very high temperature, is that of dissolving away all or most of the impurities, which are removed from the smelting furnace in the form of slag. The amount of limestone usually required to effect this result, about equals the weight of coal or coke used as fuel; it will be therefore seen how much more economically iron can be smelted when its ore, coal, and limestone are simultaneously found (as in the neighbourhood of Glasgow, &c.), than in districts (as Northamptonshire, &c.) where both fuel and flux are absent.

From the results of the analysis already given on the previous page, we may expect alumina and silica, as clay; lime, carbonic acid, carbonaceous matter, with possibly a little sulphur and phosphoric acid, in most ores. It may, therefore, be useful to some of our readers if we give an outline of a method of chemical analysis, by which some of these substances are detected; and also a simple plan of ascertaining the quantity of available iron in any specimen. Those largely engaged in practical operations need not instruction from this work, for they will employ a competent chemical analyst, to report accurately the character of any ore they may wish to examine. Our instructions are intended for those who wish to arrive at proximate results, preliminary to more careful analysis, which requires long experience to effect with accuracy. Comparatively little apparatus is required for the following method of qualitative analysis; but if a knowledge of the quantities of each substance present is desired, an accurate chemical balance is necessary; and several precautions must be taken to ensure exact results.

About fifty grains of the ore should be dried at a gentle heat, not exceeding that of boiling water. This may be done by first breaking it into small fragments, placing it in a basin or evaporating dish, and the latter in a pan of water kept at a boiling temperature. This is a form of what is called by chemists a water-bath; and its advantage is, that so long as water is kept in the lower vessel, it is impossible that the material to be dried can attain a higher temperature than that of 212°.

When quite dried the fragments are to be transferred to a mortar, and ground to a fine powder, which is to be put into a glass flask, than which nothing answers so well as a clean Florence oil-flask. To effect the solution of all soluble portions of the powder, two ounces of hydrochloric with half an ounce of nitric acid, previously mixed together (forming what was formerly termed *aqua regia*, from its power of dissolving gold), are to be poured on the powder in the flask. The contents should be exposed to a boiling heat for half-an-hour. At the expiration of that time the flask should be removed from the flame, and its contents allowed to settle. The clear liquid is then to be poured into a test-glass or jar, and the solid contents in the flask may be boiled with some more of the nitro-hydrochloric acid. This fresh solution, after settling, is to be added to the previous boiling.

By such means all the iron, manganese, magnesia, lime, and alumina—all soluble in the menstruum employed—will have been dissolved, and so brought into a condition fit for chemical testing. The insoluble matter left in the flask must be either silica (or flinty matter) or carbonaceous matter, most probably coal. Generally both are present in this residuum, which, in a qualitative analysis, may be neglected.

The clear solution in the test-glass is now to be tested as follows:—First, add its own bulk of distilled water, to dilute it. Then pour in liquid ammonia, stirring continually with a glass rod until no more precipitate is afforded. This will consist of the mixed oxides (the sesquioxides $Fe_2\ O_3$ and $Al_2\ O_3$) of iron and alumina. These may be separated by pouring off the clear liquid; pouring the remaining liquid and the precipitate on a filter of porous (white blotting) paper held in a funnel; and abundant washing with water, to remove any adherent acid. The paper, with its contents, is then to be transferred to a glass jar, and hydrochloric acid to be added until the precipitate is re-dissolved. The clear solution is to be poured into another test-glass, and caustic potass in solution added to it, the liquid being kept constantly stirred. The alkali will throw down the oxide of iron; but, *being in excess*, it will retain the alumina in solution.

The oxide of iron is thus first separated, and the liquid with it should be transferred to a filter, when the iron will be left in the latter, whilst the alumina and other matter in solution will pass through. Distilled water should be poured on the filter, so as to remove all soluble matter; and what passes through must be kept for the next step—that of ascertaining the remaining constituents of the ore.

It is first desirable that the bulk should be reduced by evaporation, which must be effected in an evaporating dish, till not more than three ounces, by measure, are left. The liquor is then to be transferred to a glass jar, and a solution of sal-ammoniac added. This will precipitate the alumina, which should be filtered, washed, and laid aside, as just directed for the oxide of iron. The filters containing each of these can be dried in the water-bath for weighing, in the manner already directed for the first drying of the ore, at the commencement of the analysis.

To the solution—thus passed through the filter, and which, to save trouble, should again be evaporated, and so reduced in bulk as just directed—a solution of oxalate of ammonia is to be added, which will precipitate the lime as oxalate of that earth. Filtering, washing, drying of the precipitate, and re-evaporation, must again be pursued.

The resulting liquid is, lastly, to be tested for magnesia, by adding to it liquid ammonia and a solution of phosphate of soda together. Thus a double phosphate of magnesia and ammonia is afforded. Filtration, washing, &c., ensue as before; and the precipitate is to be dried like the preceding.

The peroxide of iron (sesquioxide), that of

alumina (or sesquioxide of aluminium), lime, and magnesia; also oxides (protoxides), respectively, of calcium and magnesium, are thus removed. There may still be left phosphoric acid, sulphur, &c.; but it requires considerable analytical experience to detect and separate these substances, and we shall, therefore, omit notice of the method employed. As we have seen in the analysis given at p. 54, *ante*, their proportion is usually small; hence they would escape detection at the hands of any not well practised in analytical operations.

To obtain an approximate quantitative analysis additional precautions are necessary. For this purpose, ten grains of the ore are sufficient, *after drying* in the water-bath, and powdering. Each filter must be carefully dried and weighed before use; and when the precipitate is on its surface equal care must be taken in drying on the water-bath. The weight of the filter must, of course, be deducted from its joint weight with that of the precipitate. At each washing, every particle of soluble matter is to be removed by distilled water—all the washings being added to the solution that first passes through the filters; the rule being, that only the solid insoluble matter is left on the filter for drying and weighing, otherwise a wrong estimate would result in reference to the proportion of each constituent.

Of course, in the laboratory, several precautions are observed that would give far more accurate results; but it would be useless to burden our instructions, here intended for unpractised persons, with details only to be appreciated by the experienced chemist. The preceding directions need not cause any very great amount of error for an average analysis.

If ten grains of the ore be employed, the percentage of each constituent is arrived at by multiplying its weight by 10. If twenty-five grains are used, then the multiplier is 4; and if fifty grains, of course each weight must be multiplied by 2, to obtain the per-centage.

But most of those who follow these directions will merely desire to know how much available iron is contained in any specimen, and then the process is greatly simplified in obtaining approximative quantitative results. In such cases the broken ore is first to be dried, as previously directed, on the water-bath, and subsequently powdered. Fifty grains are then to be weighed, transferred to the flask, and dissolved in the acid. The clear solution is, with the solid matter, to be poured on the filter, and the solid residue carefully washed with distilled water, so as to remove into the glass jar beneath, the soluble matter as carefully as possible. The liquid thus obtained should be evaporated, ammonia added, and the alumina separated, as directed with caustic potass. The liquor is then to be poured on to a weighed filter, which will retain the oxide of iron, that must be carefully washed. The filter is then transferred to a water-bath, dried, and weighed. The weight of the filter being deducted, leaves the weight of oxide of iron obtained from the specimen.

We must next give instructions (which we shall restrict to ascertaining the amount of iron present) as to calculating quantities.

By the processes we have proposed, whatever the primary condition of the iron was in the ore, it is thus obtained as the sesquioxide; that is, two parts of the pure metal are united with three of oxygen; or, according to chemical symbols, its constitution is represented as Fe_2 (two of iron) and O_3 (or three of oxygen). Iron combines, according to the doctrine of chemical equivalents, in the proportion of 28; whilst the equivalent of oxygen is 8. It hence follows that the chemical constitution of the sesquioxide of iron may be represented in figure value, as follows:—

$$\begin{array}{lr} \text{2 of iron, or } 2 \times 28 \;\ldots\ldots & = 56 \\ \text{3 of oxygen, or } 3 \times 8 \;\ldots\ldots & = 24 \\ \hline & 80 \end{array}$$

That is, an equivalent of the sesquioxide is represented, chemically, by the figure value 80. It hence follows, that an equivalent of this oxide, 80, is to two equivalents of iron ($2 \times 28 = 56$) it contains, as the amount of sesquioxide we obtain by one analysis is to its iron; or, supposing that we obtained twenty-five grains of the oxide on the filter, we should have the following common proportion (or rule-of-three), viz.—

80 : 56 : : 24 : is to the iron present.

Working this out in the usual way, we have—

$$\frac{56 \times 24}{80} = 16{\cdot}8.$$

That is, fifty grains of the ore contain 16·8, or rather more than sixteen and three-quarter grains of pure iron. Doubling this, because we used fifty grains, we find the per-centage of iron in the specimen to be 33·6, or rather more than $33\frac{1}{2}$ per cent.

Such a plan may, therefore, be employed with but a very moderate knowledge of chemistry; and, with the exception of the balance, little apparatus in approximately ascertaining the quantity of iron in a specimen of ore. We shall omit giving directions in respect to determining the carbonic acid accurately, because much care is necessary to produce accurate results; more especially as not only will the carbonate of iron be present, but also carbonate of lime, and, possibly, carbonate of magnesia, both of which tend still further to complicate the results, and the methods of arriving at them. Our only object has been to suggest a comparatively easy mode of ascertaining the approximate amount of iron; and the determination of other constituents of ores must necessarily be left to experienced hands in chemical analysis.

Numerous other methods exist for the assay of iron ores. Some years ago, a very expeditious plan was proposed by Professor Fuchs. It depended on the fact that hydrochloric acid cannot act on metallic copper in the absence of atmospheric air. But a sheet of copper immersed in a solution of a persalt of iron (a salt of the sesquioxide), reduces the iron, by taking

a portion of the oxygen of the iron salt, and forming a protosalt of itself. According to the ratio of chemical equivalents, the protosalt of copper so formed, is equal, in quantity, to that of the peroxide in solution. For example, the chemical equivalent of solution of copper is $32 + 8 + 40$ anhydrous; that is, 32 of copper, 8 of oxygen, and 40 of sulphuric acid, form 80 parts of sulphate of copper, a protosalt of that metal. Now, as we have previously seen, the equivalent of the sesquioxide of iron is also 80; hence the quantity of protosalt of copper, found by acting on a persalt of iron, is indicative of the amount of the peroxide of this metal present; whence the actual amount of iron in it may readily be calculated from the data given at p. 56, *ante*.

The practical method of carrying out this analysis of the quantity of iron in an ore, we quote from an anonymous source, first illustrating the principle of operation, before describing the *modus operandi*.

"Into a solution of peroxide of iron in hydrochloric acid, put a piece of (pure) copper, the weight of which is accurately known; boil it well until no more copper is dissolved; weigh the undissolved copper after having cleaned (washed) and dried it; and thus ascertain how much copper has been dissolved. The quantity of peroxide of iron contained in the solution is, to that of the copper dissolved, as their respective equivalents—viz., as 5 to 4 (accurately, 40· to 31·7). Therefore, if 4 of copper be dissolved, it indicates 5 as the quantity of peroxide of iron originally contained in the solution."

So far in respect to the principle of action, which corresponds, exchanging oxide for salt, with what we have already stated. The practical directions are as follow:—

"For the purpose of ascertaining the quantity of iron contained in an ore, according to this method, proceed as follows:—Having reduced a portion—say 50 grains—of the ore to fragments (of) the size of a peppercorn, digest in a flask by a gentle heat, with rather more than a fluid ounce of hydrochloric acid, until solution takes place; then, in order to peroxidise the iron, add cautiously, by small portions at a time, 20 grains of chlorate of potass—nitric acid is inadmissible (for it would individually act on the copper, and so vitiate the result). Continue the digestion for a short time, and boil; then add a slip of clean copper, previously weighed, and which, as a precautionary measure, should equal, in weight, the quantity of ore operated on: continue the boiling for ten minutes; then remove the flask as speedily as possible, and fill it up with hot water; pour off, and remove the copper; clean, dry, and weigh it: the loss, as already stated, will indicate the quantity of iron existing in the ore under examination.

"As an example, the writer dissolved 50 grains of clay ironstone in the foregoing manner, and boiled with it a slip of copper, weighing 53·85 grains: after being boiled, washed, and dried, it was found to weigh 36·8 grains; 17·05 grains had therefore been dissolved. Now, as every 4 grains of copper dissolved, indicate 5 of the peroxide of iron (the following proportion will give the quantity of iron present): therefore—

$$4 : 5 :: 17{\cdot}05 :: 21{\cdot}31$$

or

$$\frac{5 \times 17{\cdot}05}{4} = 21{\cdot}31$$

And in 21·31 grains of peroxide, 14·91 grains of iron were present, or 29·82 per cent. of metallic iron in the ore."

In the preceding illustration, the writer from whom we have quoted assumes 27·18 as the equivalent of iron; although, by the omission of the fractional difference between the corresponding values 40 : 31·7, substituting 4 : 5, he practically arrives at the same results as we should do in considering the equivalent of iron at 28·, that we have previously assumed as correct in this work.

In certain respects there is a parallel between this method of ascertaining the amount of iron present by dissolving the ore in hydrochloric acid, and the action of copper, with that of Reinsch, used for detecting arsenic in a similar solution. We need not say that all the materials employed should be very pure. Access of air must be prevented to the copper during the process of boiling, for reasons already hinted at, as a condition of success, and the foundation of the principle of the method. "Upon adding the piece of copper to the solution, this must be immediately brought to the boiling-point, and kept there in order to prevent access of air. Previous to removing the undissolved copper from this solution, hot water is to be added till the vessel is quite full (a glass flask is best for this purpose, having a narrow neck sufficiently wide to allow of the introduction and removal of the copper); this is to be poured off, and fresh hot water added; the copper, which is generally covered with a brownish coating, is then carefully washed in cold (distilled) water, dried at a gentle heat, and then weighed. The foregoing process has this advantage, that the substances ordinarily met with in iron ores—such as silica, alumina, magnesia, lime, oxide of titanium, oxide of manganese, phosphoric and sulphuric acids, &c.—do not, in any way, interfere with the accuracy of the results. An iron ore containing arsenic, however, cannot be analysed on this principle, as blackish gray scales of arseniuret (arsenide) of copper are deposited on the metallic copper." Hence the reason we just suggested the parallel, in certain respects, between Reinsch's method of detecting arsenic, and the mode of analysis a description of which has just been quoted as the method of Fuchs.

The following illustration of the application of Fuchs' method, to the determination of both the peroxide and protoxide of iron present in a specimen, is interesting. We have added remarks parenthetically, as in the preceding quotation, for the purpose of clearing away certain difficulties.

"Crystallised magnetic iron, containing both protoxide and peroxide, was next examined. Fifty grains were dissolved in hydrochloric acid, to which chlorate of potass was added, to bring

the whole of the iron to a state of peroxide. 40·71 grains of copper were dissolved, which is equivalent to 51·36 of peroxide of iron, or 102·72 per cent. (an excess due to the peroxidation of the protoxide). Another portion of fifty grains was dissolved, without the addition of the chlorate of potass (to deal with the peroxide naturally existing in the ore); the copper taken up was only 27·1 grains, equivalent to 34·2 grains of peroxide of iron, or 68·4 per cent.; this deducted from 102·72, indicated by the first fifty grains (in which the protoxide was converted into a peroxide), gives 34·32, corresponding to 30·88 of the protoxide of iron: consequently, this mineral gave of"—

Peroxide of iron	68·40
Protoxide of iron	30·88
Loss	0·72
	100·00

This plan of analysis appears extremely easy of execution, and much more simple than the one we proposed at p. 55, *ante;* but in that, instructions were given for the testing and weighing of bodies present in ore, besides the iron.

The method of volumetric analysis has lately been applied to the assay of iron ores; and its principles and practice may be briefly explained as follows:—

If two solutions are made, in such proportions that the entire quantity of each shall exactly neutralise each other, any proportionate quantity shall produce precisely the same result. Thus, supposing forty-nine grains of sulphuric acid, composed of sixteen of sulphur, twenty-four of oxygen, and nine of water (these being the equivalent number of each, except that of oxygen, which is present in a triple proportion, or 3×8, the latter number being that of its equivalent), be mixed with distilled water, so as to make a solution divisible into 1,000 parts; and, secondly, that another of pure anhydrous caustic soda be made so that thirty-one grains are dissolved in an equal quantity of water, as we have mentioned in regard to the sulphuric acid; it will follow, that 1,000 measures of each will exactly neutralise the other, the proportion of acid to soda being in the ratio of 49 to 31. In other words, thirty-one grains of the soda, united with forty-nine grains of, what is called in chemistry, hydrated sulphuric acid, exactly neutralise each other, producing a neutral salt. If, therefore, the 1,000 measures of each completely neutralise the other, any equal multiple of them would do the same. Thus 100 measures of the one added to the other would have the same effect as five measures of each—indeed, any similar number. Now such solutions, perfectly pure, are called test solutions, and they may be variously employed to test the value of other solutions; for it is evident that, if instead of using a solution of pure soda of the strength we have named, one much weaker was employed, of course less sulphuric acid solution, by measure, would be needed to neutralise the soda in the fresh sample. If, for example, the same weight in a specimen of commercial soda required only half as much sulphuric acid to neutralise it as does the pure specimen dissolved in the thousand measures, it is evident that only half as much soda can be present; that is, there would only be $\frac{31}{2} = 15{\cdot}5$ grains in that specimen. This method would therefore show that the commercial sample is pecuniarily of only half the value of that found in the test solution of the chemist; and so on, in the same ratio, proportion, or per-centage, for other numerical results.

It will be therefore evident that we may make solutions of such a strength that their mutual powers of neutralisation shall become a test of their chemical, commercial, and, therefore, pecuniary value.

At the same time there must be some indication of the moment at which neutralisation takes place. In the instance we have adduced, a little tincture or infusion of litmus is employed, which retains its blue colour so long as no free acid is present, but instantly turns red if such occur. And, *vice versâ*, if first it was reddened with an acid, the moment neutralisation takes place, its blue colour is restored. A careful attention to the moment of neutralisation, at which the addition of the test solution must *instantly* cease, is essential to the success of the operation. It is also necessary that constant stirring of the liquid under examination be resorted to, for the purpose of equalising the action of the two substances on each other throughout all parts of the vessel (which, of course, must be glass) that contains them. The numerical result is indicated by the number of measures read off, in respect to the test solution employed, as we have, in part, stated when considering the relative value of a specimen of soda, requiring but half the quantity of acid that a pure article would require for neutralisation.

Now, applying the same principle to an assay, or volumetric analysis of an iron ore, we may, so far as the iron alone is concerned, obtain very satisfactory and immediate results. In fact, the value of the system of volumetric analysis depends on the speed with which the results are obtained, and the ease with which a person almost devoid of chemical knowledge may arrive at a satisfactory solution of questions that, by other methods of analysis, would require long experience in the laboratory.

One test, and an indicator in the case of volumetric analysis of iron ore, is the permanganate of potass. It has a reddish or purple colour when in solution; but added to a *proto*-salt of iron, it loses that colour, owing to partial deoxidation. It may hence be poured into a solution of a protosalt of iron, until complete peroxidation of the iron is effected *by it,* and so used as a test of the presence of iron in solution in a protoxide state. We italicised the words *by it,* because if any nitric acid, chlorate of potass, or other agent were present, that could, *per se,* oxidise the iron beyond its first stage of oxidation, the permanganate of potass would be valueless as a test. The moment a pinkish

colour appears in place of a clear colourless solution, it is a sign that the peroxidation of the iron is complete in any solution; and, as we shall presently explain, the amount of the permanganate requisite to effect this result, by measure, becomes an indication of the amount of iron present in the solution.

In a very similar manner, and for identical reasons, a solution of bichromate of potass may be used to test solutions of iron ore, because it converts, as does the permanganate of potass, the protoxide into the sesquioxide. But, in this case, a separate indicator must be used; and this is the *ferri*-cyanide of potassium, or, as it is sometimes called, the red prussiate of potass. This salt gives a blue precipitate with a protoxide of iron, but only communicates a red colour with a persalt, or rather, to iron solutions in which the metal is in a state of sesquioxide. Hence a test of solution of bichromate of potass is added to the solution of iron only so long as a drop on a plate of the latter gives a blue colour with the ferricyanide solution, which then becomes the indicator of peroxidation on ceasing to afford the blue tint.

The strength of the permanganate of potash solution may be in the proportion of 31·6 grains to 7,000 grains, or one pound avoirdupois of distilled water. That amount is equivalent to 56 grains, or two equivalents of iron; a single equivalent of the metal being equal to 28, as already stated. If 56·43 grains are dissolved in the same quantity of water, that quantity will be equivalent to 100 grains of iron in solution as a protoxide or protosalt; and this measure, of course, will give per-centages at once, without the necessity of calculation. In using the permanganate, the ore must be dissolved in sulphuric acid, excluding all access of atmospheric air, lest oxidation of the protoxide take place independent of the action of the permanganate of potash; and special apparatus ensuring this result should be arranged so as to entirely prevent risks of accidental oxidation. "One equivalent of permanganate of potash acts upon ten equivalents of iron, or 158 parts of permanganate upon 280 parts of iron. The 10 atoms of iron require the presence of 8 atoms of free sulphuric acid. Less than 8 atoms will not ensure the purpose; and a great excess leads to errors." The following table is quoted, as are the preceding remarks, from Mr. J. T. Griffin's *Chemical Handicraft*—an excellent practical guide on the purchase and use of apparatus. The table shows how much permanganate used indicates iron present:—

Permanganate in Grains	Iron present and indicated.
·5643	1 grain.
2·8215	5 ,,
5·6430	10 ,,
28·2150	50 ,,
56·4300	100 ,,

Guided by this table, an empirical solution may be made; and, according to its strength, the number of measures used will become a volumetric guide to the quantity of iron present in any tested solution. The mode of using such solution was described when we illustrated the principles of volumetric analysis by the instance of sulphuric acid and soda, at p. 58, *ante*.

In respect to the bichromate of potash solution—which has a similar action to the permanganate, and requires, as just stated, that the progress of peroxidation should be continually tested by ferricyanide of potassium, which, on ceasing to give a blue colour, indicates peroxidation—the following table, also quoted from Mr. Griffin, will be a guide to making the solution:—

Bichromate used.	Iron present and indicated.
·878	1 grain.
8·780	10 ,,
43·900	50 ,,
87·800	100 ,,

From the quantities in the first column any strength of bichromate solution may be made. "For every 6 atoms of iron present, there must be added 7 atoms of free hydrochloric acid to afford hydrogen, to take up the oxygen of the chromate."

As the bichromate requires a separate indicator, the method of using it may be as follows. Dot, at short intervals, a white slab or plate with a weak solution of the ferricyanide of potassium. From time to time, as the bichromate solution is added to that of the iron, stir up the liquid, and remove one drop at the end of a fine glass tube to the plate, dropping it into the dots of ferricyanide solution, and taking care to wash the end of the tube before each time of using it. At last the blue ceases to be produced, and, consequently, all the protoxide of iron has been converted into peroxide.

In clever hands these methods of volumetric analysis afford good results after some practice; but, of course, they only indicate the amount of protoxide; and therefore, if the peroxide is present (as was illustrated in the case of an ore of iron, in an analysis given at p. 54, *ante*), it would not be indicated at all, unless first reduced to the condition of protoxide by heating with a mixture of iodide of potassium and hydrochloric acid, and testing the free iodine by hyposulphite of sodium. But this is a far more intricate method than that proposed by Fuchs, which we should therefore preferably recommend to those who have but a moderate knowledge of chemistry (see *ante*, p.p. 56, 57).

By volumetric analysis we simply deal with the iron present; by the method of Fuchs it is also alone considered. By that we suggested at p. 55, *ante*, the iron, lime, magnesia, and alumina, might all, but separately, be examined, weighed, and determined. But, lastly, in that and each of the analyses, there is left to determine the amount of silica and carbonaceous matter present. For this purpose the following method may be adopted:—

Digest fifty grains of the dried and powdered ore in nitro-hydrochloric acid twice, successively, as directed at p. 55, *ante*, in a Florence flask; pour off the clear solution, and wash

abundantly with water the solid residue, which should be first thrown on to a weighed filter. The insoluble matter thus retained will only contain (except in rare cases) silica and carbonaceous matter. The filter is then to be removed, dried, and weighed with its contents. It must next be ignited in an open crucible, until all appearance of blackness is entirely removed. By this the charcoal, both of filter and the carbonaceous matter of the ore, will be dissipated as carbonic acid gas, and nothing will remain but the ashes of the filter and the silica of the ore. The silica is then to be weighed; and deducting this from the weight of the filter and its contents, less the weight of the filter itself, the quantity of carbonaceous matter in the ore is ascertained. But, to be precisely accurate, another filter, of exactly the same weight, should be burned, and its ashes carefully weighed. The result is to be deducted from the weight of silica obtained as above, because that will be just as much in excess of the truth by the addition of the ashes of the filter with which it was burned.

It is evident that this process may either be made a separate operation, or conclude the systematic analysis that we recommended at p. 55, *ante*.

The limits of this work forbid us entering into more minute details in respect to the various and exact analytical methods that have been proposed for analysing iron ores; and especially the estimate of the manganese present, which, in a species we shall presently describe, is a most important and highly valuable addition to the ore, especially for making steel. We can only, therefore, refer our readers to elaborate treatises on analysis, qualitative and quantitative—such as those of Mohr, Fresenius, Rose, and others, in which the subject is exhaustively dealt with. We may add, however, that the practice of methods recommended by them requires most careful manipulation, specially arranged apparatus, and, above all, much experience in laboratory processes, generally beyond the reach of those we are addressing.

Lastly, before concluding our notice of iron ores and their analysis, we must notice one that has become very celebrated, as affording a most valuable material for the steel-maker, according to the old method, and those who follow the Bessemer process—that most remarkable application of pure science to practical purposes. For both of these manufactures a certain amount of manganese, as previously mentioned, is requisite. This metal might be added for the purpose; but, for some time past, a peculiar kind of iron, containing manganese, has been adopted with the best results. Although opinions are divided as to whether the metal known as "Spiegeleisen" really owes its valuable qualities to a per-centage of carbon (about 5 per cent.), or to the presence of manganese, ranging between $3\frac{1}{2}$ and $11\frac{1}{2}$ per cent.—this question we shall not at present discuss, as it will more conveniently be considered in connection with the manufacture of steel. We are indebted to the columns of *Engineering*, one of our chief engineering journals, in which these subjects are constantly discussed in detail, for the following description of, and remarks on, the ore of this metal, and other particulars of essential interest to the practical man:—

"Spiegeleisen is made in comparatively few localities only; and it requires for its production certain distinct kinds of ores, containing both iron and manganese, and entirely free from sulphur and phosphorus. The chief iron ores used at present to produce spiegeleisen are spathic ore [see *ante*, p. 52, for the British kind], and the brown ironstone formed from the same, and the Franklinite of New Jersey, in America (United States).

"The principal localities for spathic ore in Europe, are the Erzberg, or 'ore mountain,' in Styria; a mountain of the same name in Carinthia; and the Stahlberg, or 'steel mountain,' of Müsen, in Rhenish Prussia. Brown ore, formed by decomposition of spathic ore, exists in the mines belonging to the Georg's Marienhütte, in Hanover; and in the vicinity of Schmalkalden, in Thuringia. Almost all the 'spiegel' imported into England is made in Rhenish Prussia, from the spathic ore of the Stahlberg. This ore is found as a hard, solid, crystalline mass, forming a large seam in the primary rock of the mountain; it is worked by several parties, the principal of which is the Cologne-Müsen Company, that owns four-fifths of the total mine. The workings of this company are very extensive. The main working shaft is horizontal, being driven into the mountain from its side [see remarks on adits, at p. 41, *ante*], and below the original workings, which were carried on in shafts and galleries commenced in the middle ages, and worked ever since. The ore is brought to the mouth of the shaft in trucks, running on rails, similar to those employed in coal mines. It is then broken into pieces of the size of a fist, and these are carefully assorted by hand, according to their contents of copper ore or pyrites; which, occurring in specks of considerable size, are easily detected and picked out. This labour is amply repaid by the copper obtained from smelting the copper ore, and also by the improved quality of iron produced by the removal of copper. Almost all the ore used for making spiegeleisen is calcined before smelting. This operation is performed in open kilns, of a cylindrical shape, about ten feet in diameter, and sixteen feet high. Alternate layers of raw ore and coke cinders, or charcoal refuse, are piled up within the kiln, and the whole is fired from the bottom. From time to time the lowest layers of calcined ore are raked out, and fresh charges added at the top, which, in their turn, are calcined in the descent, the kiln being in continuous action. There are several other kinds of kilns employed for the same purpose in Siegen. The calcined ore from the Siegen district is an important article of trade in Germany. It is brought by railways, canals, and rivers, to all parts of Westphalia, and particularly to the blast furnaces in the Ruhr district; * * * * and is almost indispensable for mixing with the inferior ores from

Nassau and the Ruhr districts, in the production of the better qualities of pig-iron. In exchange, coke from the Ruhr is carried to Siegen, to be mixed with charcoal in the manufacture of spiegeleisen. There are two or three furnaces in the Siegen district which use pure charcoal in the smelting; but their production is very limited; and as the spiegeleisen is run into broad slabs which bear no mark, it is next to impossible to buy *bonâ fide* charcoal-spiegel in the English market. These blast furnaces appear to be more of an exhibition article, since it is obviously necessary for parties pretending to sell charcoal-iron, to have, at least, one furnace in blast wherein pure charcoal is employed.

"There is, indeed, no great difference in the value of charcoal-spiegel and coke-spiegel iron, for the purposes to which they are now principally employed—viz., in the Bessemer process; and the use of coke in Siegen is therefore in no way objectionable. It is difficult, however, to produce spiegeleisen with pure coke; and hence the practice of mixing coke and charcoal. To obtain spiegeleisen from a suitable charge of ore, it is necessary to protract that part of the smelting process which is designated as carburisation, and which immediately precedes the fusion of the iron. This carburisation must take place at a temperature which is not sufficiently high to reduce silicon from the slag, since the presence of a considerable per-centage of this element would drive the carbon out of its combination, and change it into graphite (a carbide of iron). The iron, instead of being specular, would then become gray or mottled, according to the temperature in the furnace. If, on the other hand, the time of carburisation is too short, or the temperature too low, common white iron will be produced, containing only a small per-centage of combined carbon, and very little manganese, which latter requires a greater heat for reduction. The whole art in producing spiegeleisen used to consist in making the ore capable of quick reduction by calcination, using burnt lime, and only a small quantity of clay-slate as flux, in order to reach the stage of carburisation as quickly as possible, applying cold blast and charcoal, in order to keep down the temperature of the zone of fusion, and thereby protract the preceding stage to the utmost degree possible. With recent improvements, and the necessity for economy, the iron-masters of Siegen have learnt to make spiegeleisen with hot blast and coke, with utilisation of waste gases, and a high temperature in the zone of fusion. This is done principally by keeping out the silicon with an over-dose of burnt lime, which also assists in preventing the sulphur from the coke acting injuriously upon the iron.

"With all these precautions, however, it is not possible to produce spiegeleisen at all times, and continuously, in the same furnace. Fluctuations in the temperature and pressure of the blast, and similar apparently very slight causes, will suddenly change the produce from spiegeleisen into gray or mottled iron, if the heat is excessive, or the slag too rich in silica, or the coke too much contaminated with sulphur: common white iron will be produced if the temperature gets too low, or the burden too heavy. With the best-managed blast furnaces, intended specially for making spiegeleisen, only 70 or 80 per cent. of the total annual produce is iron of that class, the remainder being either gray or white, according to the side to which there is a greater liability of errors with the particular furnace. Attempts have been made artificially to increase the per-centage of manganese in some kinds of iron, by adding manganese ores to the charge in the furnace. They have not, however, proved successful as yet; so that the per-centage of manganese in the spiegeleisen may be said to be beyond the control of the iron-masters, so far as the production in the blast furnace is concerned."

The lengthened notice that we have thus given of the ores of iron is fully justified by the importance of the subject; for, as we have frequently observed, iron is to this country of infinitely greater value than its bulk of gold, leaving the question of weight unconsidered. It will be seen, from a perusal of the preceding pages, how varied are the conditions, geological, physical, and chemical, in which the various sources of the metal are found; and whilst we have endeavoured to be as explicit as possible, so far as our limits permit, we cannot but confess that many important particulars have been omitted, that, had the space at our disposal allowed, would have received full notice. A work several times the size of the present one, might have been profitably devoted to an exhaustion of subjects pertaining to the manufacture of iron; and the fact, attested by the extent of some splendid publications on the matter, and published at an almost fabulous price, is quite a sufficient apology for any meagreness of detail that may possibly be assigned to our discredit.

Before entering on a detailed description of the iron manufacture, it may be interesting to give abstracts from a report on the Mineral Sources of the United Kingdom, issued by the Board of Trade for 1879. In the introduction there is given a table showing the substantial agreement of the voluntary returns to the Mining Record Office of the output of coal with those compulsorily returned to the Inspectors of Mines. And there is also a table showing the railway movement of coal during the same year, which may be summarised by the statement given a little later. The total value of the minerals produced was £55,733,967—a fair average value when the declension in price is borne in mind. Taking the tables in order, we find that of tin ore (block tin) 14,665 tons were returned from the mines and works of Cornwall and Devon—some 400 tons less than in the previous year, but of a higher value, owing to the heavy increase in price during the latter part of the year. Of copper ore, 51,032 tons were raised—three-fifths in Cornwall, Devon being the only other large contributor to the output—and the total being 5,000 tons less than in the previous year. Of lead ore, 66,000 tons were raised —10,000 tons less than in the previous year—Wales, Durham, and Northumberland being the

chief producing districts. Of zinc ores, 22,199 tons were raised, the Isle of Man, Denbighshire, and Cornwall being the largest producers. Of pyrites, 20,000 tons were produced—Ireland being the largest contributor. Of the miscellaneous minerals, it is only needful to say that 447 oz. of gold were raised, chiefly in Merionethshire; as well as 27 tons of silver ore—from Cornwall. Coming to the iron ore produce, we find that the total yield of British mines was 14,379,735 tons. Of this 5,130,849 tons were obtained from coal measures—West Scotland and North Staffordshire taking the lead in the production of this class of ore. Of that obtained from mines and workings not in the coal measures we have fuller details. As is well known the Cleveland district takes the lead in the production of this class of ironstone—in 1879 from twenty-nine mines 4,750,000 tons being raised. Next follows Cumberland with 1,227,006 tons of its rich ores, Northamptonshire with 1,211,406 tons; Lancashire with 976,822 tons; Lincolnshire with 695,326 tons; Ireland with 155,833 tons, and several other counties or districts, all yielding less than 100,000 tons each. The value varies—the rich hematite ores standing highest, and those of Cleveland about the lowest in the scale—the total value being £2,397,010, to which is to be added that of the argillaceous and blackband ores obtained from the coal measures, giving a gross total value of ironstone raised in the kingdom of £4,962,434. There are tables showing the railway distribution of the ore, but these need not here be summarised. To the 14,379,735 tons of ore raised, there is to be added that of the burnt ore from cupreous pyrites—332,300 tons, and 1,085,045 tons imported, which give the total smelted of 15,797,080 tons of ironstone. The bulk of the imports were from Bilbao—Cardiff, Newport, Newcastle, Middlesbrough, Sunderland, and other ports taking the bulk of these importations in quantities from 299,085 tons to 144 tons.

Appropriately this table is followed by one giving the amount of pig iron produced. There were 343 furnaces in blast in England, making 4,374,526 tons of pig iron, 57 in blast in Scotland, producing 932,000 tons; and on the average of the year 96¾ in Wales yielding 688,811 tons, so that the total production of pig iron was 5,995,337 tons, a diminution from the quantity for the previous year. The average make per week of the furnaces in blast was also less, in England by 9 tons weekly, and in Wales by 23 tons weekly, whilst in Scotland there was an addition of two tons to the weekly average output of the furnaces over the whole of the year. Yorkshire has still the largest output, the North Riding yielding 1,210,091 tons from the 70 furnaces in blast; Lancashire 631,343 tons from 37 of its hematite smelting furnaces; Durham and Northumberland 557,255 tons from 33 furnaces; and Cumberland 531,638 tons from 27½ furnaces, being the districts that follow that of Cleveland proper. In Wales, Glamorgan, and Monmouth yield the chief part of the make; and in Scotland, Lanarkshire and Ayrshire being the chief producers. During the bulk of the year the market prices for pig iron increased, the figures for the last week of the year being in each case the highest. In the manufacture of the 6,000,000 tons of pig iron, 13,117,411 tons of coal were used, coke being computed as coal in the return. Of the mills and forges, it may be said that 314 works sent returns, these works including 5,149 puddling furnaces, and 846 rolling mills, and of that it is apparent that there had been a change for the better in the year, though in most of the districts there were still many mills not at work. There were 28 firms who were manufacturers of steel by the Siemens and Siemens-Martin processes, the most notable additions being the Consett Iron Company, and the West Cumberland Iron and Steel Company, who were thus introducing that process to new districts. Seven firms are recorded as employing the Siemens regenerative gas furnace for melting steel in crucibles, whilst four others have regenerative gas heating furnaces. Finally there were 27 works having Bessemer converters in Great Britain, the chief additions to the list being the Darlington Iron Company, and the Erimus Steel Works, by which the production of the Cleveland district is being enlarged.

Coming to the coal returns we find a substantial agreement between those of the Mining Record Office and those under the Coal Mines Act to the inspectors. The number of collieries is returned as 3,877, the output of the year at 134,008,228 tons. The tendency in price seems to have been slightly upwards during the year. Northumberland and Durham are still the most productive, the yield from the 363 collieries in these counties being 29,552,079 tons, the largest portion of which is directly and indirectly used in the iron trade of the north, and of the Furness and Cumberland districts. Cumberland and Westmoreland yield from 36 collieries 1,463,867 ton; Cheshire, 720,350 tons from 26 collieries; Lancashire, 18,612,345 tons from 541 collieries; Yorkshire, 16,030,944 tons from 528 collieries; Derby, Notts, Warwick, and Leicester, 13,794,644 tons from 333 collieries; South Staffordshire and Worcestershire, 9,350,000 tons from 425 collieries; North Staffordshire, 4,025,535 tons from 144 collieries; Shropshire, 854,380 tons from 62 collieries; and Gloucester and Somerset, 2,018,648 tons from 140 collieries. From North Wales we have 2,219,682 tons from 105 collieries; and from South Wales 13,126,397 tons from 325 collieries. East Scotland yields 11,300,567 tons from 312 collieries, and West Scotland 6,169,360 tons from 361 collieries. Beyond the fact that 16,442,296 tons of coals, cinders, and patent fuel were exported to foreign countries, and that 10,058,811 tons were received into the metropolitan district, we have no general facts as to the use of the large quantity of coals produced in the kingdom.

Of porcelain clay and china stone, fire and potter's clay, 519,744 tons were produced from Cornwall, Devon, and Dorset; and fireclay from many counties over 2,300,000 tons, Durham and Northumberland coal pits taking the lead. Of

salt, 2,558,368 tons were produced ; of barytes 19,349 tons ; and of jet 6,720 lbs. ; the last being the only return of jet that has been made for some time. It is not needful to give the small quantities of the miscellaneous minerals, for the above list indicates with tolerable fulness how largely we have been drawing on our mineral resources for some time. And it is probable, owing to the enlarged demand for iron that has been known during 1880, that the total output for that year will be proved to be even larger. If the full measure of power that these minerals represent were used, the large output might be looked on with satisfaction, but this is not yet the case, though there has been progress in this direction of recent years.

We have already frequently referred to the necessity of ventilation of mines (see p. 13, *ante*). This partly arises from an increase of temperature as we descend into the earth, and is especially remarkable in the case of the copper mines in Cornwall, &c., (see *ante*, p. 43). The most recent addition to our knowledge of this subject was given towards the close of 1880 by Mr. Herbert Woodward, in a paper read before the Manchester Geological Society, entitled "Notes of Temperatures of Strata in the Newtown Colliery Sinkings of the Clifton and Kersley Coal Company." The notes were from sinkings which had been carried on for several years past, up to November, 1880, by Mr. F. A. Woodward, civil and mining engineer, and in the course of the paper the writer stated that they had got down to a depth of 200 yards before the experiments were commenced, having previously taken only a few observations. The holes were drilled as soon as possible in the newly exposed face of the rock, some vertical in the bottom of the shaft, and others horizontal in the sides. The shafts did not make much water, so that most of the holes were dry or nearly so, which was favourable to the observations being taken. The shafts were sunk on an average at the rate of one yard per day, so that the measure had little time for cooling. The height of the shaft was 286 feet 8 inches above the sea level, and the depth below the sea level at the bottom of the shaft 1,428 feet 8 inches, so that the total depth from the surface was 1,715 feet. The temperature of the working places would be effected by the air blown down by the Schiele fan, and also by the air from the compressors which drove the Burleigh rock drills, because as the blast became too hot the sinkers used to let the compressed air, at a pressure of 60 lbs. per square inch, blow into the shaft, and this had a rapid cooling effect. The writer then proceeded to give a tabulated statement of the results of the observations taken as the sinking proceeded, and from these tables he got the following results. The average temperature of the coal seams increased 1 deg. Fah. for each 55 feet of vertical sinking, or he might say for each $54\frac{1}{2}$ feet exactly ; the average temperature of the rocks and metals 1 degree for each 69 feet sunk ; and the average for both rocks and coal measures was 1 degree for each $61\frac{1}{10}$ feet sunk. At the depth of 1,433 feet they came upon a bed of sandstone rock, between 50 and 60 yards in thickness, and the temperature in this remained constant at 78 degrees Fah., until they got within 21 feet of a seam of coal 6 feet thick, when the temperature began to rise until they had passed through this seam, and through a 2 feet seam some yards below the 6 feet seam, where they recorded the highest temperature—viz,, 82 degrees Fah. This was the most "fiery" seam met with. They sunk the shaft, as already stated, up to a total depth of 1,715 feet, into rock, and the temperature was exactly the same as that in the bed of rock at the depth of 1,602 feet, viz., 78 degrees Fah. Ten months after the sinking had got to the Trencherbone Mine he had the temperature again taken in the coal, and the rock below the coal, and he found the coal had cooled down 3 degrees Fah., and the metals $2\frac{3}{4}$ degrees, at a depth of 500 yards, or 1,680 feet. He also applied the same test to the Doe Mine, at a depth of 1,294 feet, and found the coal had cooled 3 degrees, and the metals 2 degrees, in twenty months. This looked as if the deep seam were cooling the more rapidly of the two. The temperature of the working places in the shaft was generally six or seven degrees below that of the surrounding rocks or coal, but this was not reliable, as it would vary very much according to the quantity of air blown down. The various tests were very carefully taken, and in some cases verified two of three times over. He was, however, sorry that he did not apply the pressure guage to the drill holes where gas was given off freely, as he had little doubt that it was giving off a very considerable pressure, from the way in which it lifted the metal when near a seam of coal, and the great compression might have had the effect of raising the temperature. From the experiments it appeared that the more "fiery" the mine the higher its temperature, and in approaching the coal seams the temperature of the rocks increased more rapidly the nearer they got to them, and as gas was given off into the drill holes. The average temperature of the earth was about 50 degrees Fah. at a depth of 50 feet, and at that depth remained constant. The rate of increase in our coal-mines as generally given was 1 degree Fah. for each 60 feet, but it was questionable whether, after a great depth had been reached, the rate of increase did not become much more rapid. At Rose Bridge Colliery, near Wigan, 403 fathoms deep, the average rate of increase was 1 degree Fah. for each 56 feet, and Mr. Dickinson, in his report to the Royal Commissioners, gave it as 55 feet. At the same colliery, at a depth of 2,519 feet the heat was 92 degrees Fah. ; at Clifford Copper Mines, 440 yards deep, they found 100 degrees Fah. in 1863, and in July, 1864, it fell to 83 degrees, or 17 degrees in 12 months. At Newtown, at 1,715 feet, it was 78 deg., a difference of 14 deg. in 713 feet, as compared with Rose Bridge, or 1 deg. for 150 feet. The temperature of the earth in this country was estimated to be 98 deg. Fah. at a depth of 3,000 feet, and increased 4 per cent. at a further

depth of 420 feet. From his experiments it would be 99 deg. Fah. at a depth of 3,000 feet if it continued to increase at the same rate as in the 1,715 feet sunk through at Newtown. It seemed to him, as the result of these experiments, that they might get a very much higher average temperature if they had "fiery" seams, and a large number of seams in a shaft, as in the case at Newtown, where they passed through two seams of coal in 1,100 feet, and each seam was from 1 to 2 degs. higher than the measures above and below it, and in two cases 4 to 5 degs., which naturally tended to raise the average temperature considerably, and that they would get a much lower temperature where the seams were more widely separated by thick beds of rock or metal. He did not know of any observations where the temperature of the coal seams and rocks had been kept separate, but if the same rule held good in the measures in other places as they had found at Newtown, the only conclusion they could come to was that the temperature of the seams of coal was much higher than in the surrounding measures.

Smelting, Etc., of Iron Ore.

Theoretically, the reduction of iron ore to the metallic condition presents no difficulties, for it is only required that the earthy matter should be removed by a suitable flux, which, in the laboratory, on the small scale, in a crucible and powerful blast furnace, although a tedious operation, still is so completely under control as to be merely a question of time and patience to obtain successful results.

Practically, on the large scale, the reverse is the case; for as tons of material, frequently of uncertain composition, are acted on at once, any variation in quality of either ore, fuel, or flux induces conditions that materially affect the amount of metal produced, and consequently the profit of the undertaking. As the production of iron is so largely distributed throughout the country, although there may be no competition between the makers in any individual district, still separate districts, necessarily, must compete with each other both in quality and price. Hence the necessity of careful attention to the conditions just referred to, as affecting the amount and quality of the article produced, and also its cost. These disturbing circumstances, as we shall presently notice, are due to a variety of circumstances, some of which may be controlled; but others, as yet, are left, in a measure, to chance in their result for good or bad to the smelter.

Before entering into minute particulars on this and various other questions pertaining to the practical details of smelting, we will first glance at the appearance of the works in which the operations are carried on, and also give an outline of the processes.

A first visit to an extensive iron-smelting works, by day or night, cannot but strike the stranger with the novelty of a sight nowise paralleled in any other branch of manufactures. There seems to be neither a beginning nor end of the place. In all directions railways enter or leave the works. The locomotives, generally belonging to the firm, are drawing in coal, coke, or limestone; and, on the other hand, the "pig" is being withdrawn, to send to the nearest and best market, or probably for export. Stores, small huts used as offices, &c., are strewed, apparently hap-hazard, over the ground; and yet, except at the time of withdrawing the melted iron from the furnace, there does not seem to be any very large amount of business going on. The first object to which the visitor's attention will probably be drawn is the steam-engine, that works the blowing machines to supply air to the furnaces. Its size will, of course, depend on the extent of the operations carried on. Its duty is to work large pumps, for such are the cylinders seen near the engine. These pumps, drawing in the atmospheric air, drive it, by means of a large pipe, to an extensive reservoir, much resembling a large steam-boiler. Here the air is stored, or rather steadied in its progress; for the office of this reservoir is to do away with the irregular jerking that each successive influx of air into it from the pumps would cause, and which, if directing their blast at once to the furnaces, would afford a series of puffs, like the ordinary bellows, in place of the regular stream that is produced by the elasticity and resistance of the air in the reservoir. The effect is precisely similar to that we see in the ordinary force-pump, which, being fitted with a separate air-vessel, delivers the water in a regular stream, well illustrated in the fire-engine: but without the air-vessel, or condenser, the flow of water would be by jerks, as in the common pump.

The air is admitted into the lower part of the furnace by means of branch pipes—two or more, called, technically, *tuyeres* or *twyeres*; which, in fact, in shape and office, correspond to the nose of the ordinary bellows. Fig. 92 represents the situation of these at the base of furnace. But,

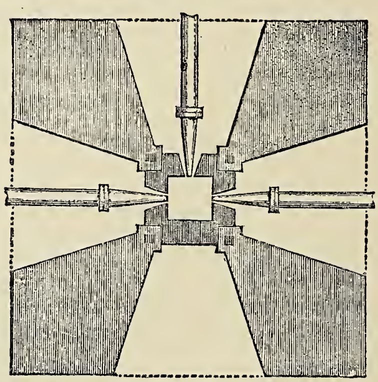


Fig. 92.—Plan of Blast Furnace, with the Tuyeres.

before reaching the furnace, the air is often raised to a temperature of about 600° or 1,000°, by being made to pass through pipes externally heated by a small furnace. The effect of this is greatly to economise the production of iron; its result is called the *hot blast.* The method

was invented by Mr. Neilson, of Glasgow, about the year 1829.

Numerous patents have been taken out for improving the methods of heating the blast of air before its admission to the furnace. One of the most successful methods is that of Mr. Player, of Stockton-on-Tees, and it has been largely adopted in the Cleveland and other iron districts. The inventor scientifically divides, or rather multiplies, the heating surface over which the cold air has to pass whilst being heated; and by his method, either coal or the waste gases from the top of the smelting furnace, may be employed for heating the air. Each stove contains thirty-six pipes, which, in one arrangement, are twelve inches in diameter, and fourteen feet high, enclosed in an external frame, within which, and around the air tubes, the waste gases or coal heat can circulate. The pipes are placed vertically in the heating furnace, in rows of six, and connected alternately at the top and bottom, so as to ensure a circulation of the air to be heated throughout the whole of the pipes between the reservoir and the tuyeres that carry it to the smelting furnace. The top of the chimney of the furnace is fitted with a damper, that regulates the heat whether the waste furnace gases or coal heat are employed. A temperature of from 1,000° to 1,200° can be thus given to the air; and so thoroughly is it thus heated, that with a 4-inch nozzle and a blast or pressure of $3\frac{1}{2}$ pounds per square inch, zinc can be melted with the hot blast four inches from the apertnre of the tuyere conveying the air outwards. An increased production has also resulted in certain cases of iron smelted with the same amount of fuel, owing to the higher and constant temperature that this heating stove, or oven affords.

The blowing apparatus and reservoir have been briefly described, in relation to their scientific principles. Of course, the size of the cylinders, pumping in the air, and driving it to the reservoir, that of the latter, and the power of the steam-engine employed, are all matters that vary, essentially and relatively, with the extent of the works, and the number and capacity of the smelting furnaces in operation at any establishment. The blowing-cylinders are fitted with valves, to admit of the entrance of the air from the external atmosphere, and the exit of the same through a pipe to the reservoir. At the Lilleshall iron-works, the blowing-cylinders for five cold blast furnaces, are each 86 inches in diameter, with a stroke of 8 feet 6 inches. The pressure of air, as it enters the furnace, is $3\frac{1}{2}$ pounds per square inch. The cylinders of the steam-engine working these are 40 inches in diameter, with 8 feet 6 in. stroke, and are worked with a pressure of 35 pounds of steam, running at 17 strokes per minute. The steam is supplied by five Cornish boilers, each 31 feet long by 7 feet 7 inches in diameter.

The furnace itself is peculiarly constructed, for it must be of great strength, and capable of resisting the enormous heat that is constantly kept up in its interior. They are made both square and round; but the latter shape is the most usual. The height, on an average, may be taken at sixty feet; but still higher have been constructed. Externally it is formed of the best ordinary brick; but internally it is lined with what is termed fire-brick, that long resists the intense heat without either cracking or melting. It gradually narrows towards the bottom, at which is a square chamber, about a yard each way, and called the hearth. It is here that metal collects; and the bottom of the furnace is closed until the time of tapping at this part, except where the tuyeres enter to supply the air from the blowing engine. A section of one of the older forms of this furnace is given at p. vii, Fig. 3, in our introductory remarks.

In this kind of smelting furnace, the top is open as represented in Fig. 93. But now the heat that used to pass away wastefully is utilised to produce steam for working the steam-engines required in the works. These will be fully illustrated and described hereafter.

The top of the furnace is open: and it is here, at a height of perhaps fifty or eighty feet from the hearth, that the materials are supplied to the furnace. They are raised from the ground to a tramway that leads to an opening in the side of the top of the furnace (see Fig. 93); and, by an

Fig. 93.—The Top of a Smelting Furnace.

ingenious method, they are tilted over into the burning mass in its interior. Before, however, being so raised each lot is carefully weighed, for the success of the smelting operation essentially depends on a due adjustment of the proportion of ore, fuel, and flux—usually limestone. These proportions great vary for different kinds of ore, as we shall hereafter more fully point out. As an example, we may mention an ore that requires 20 cwt. of coke, and 25 cwt. of limestone, to $2\frac{3}{4}$ tons of ore to produce one ton of metal. The charges of coal, ore, and limestone, are constantly, but successively, added in this manner to the contents of the

furnace; and the operation never stops night nor day, so long as the furnace is not "blown out"—that is, when its operations are entirely suspended either by accident or through badness of trade.

Of course, the materials accumulate to an enormous extent, perhaps 100 tons of the material being contained in it at one time. The effect of the intense heat is to cause the carbon of the coal or coke to combine with the oxygen of the oxide of iron to form carbonic acid gas, that escapes into the air; whilst the iron, being thus freed from this oxygen, falls down gradually into the hearth, and there accumulates. The object of the limestone, or other flux, is to dissolve all the earthy matter, particularly described at p. 55, *ante*. It thus forms what is called a slag, that falls down also in a melted state; but, being lighter than the metal, it swims on the surface of the latter.

Twice in the twenty-four hours of each day—say at six in the morning and evening—the furnace is tapped. This is effected by removing a clay stopper—one to remove the slag, which is conveyed away as waste in iron carriages; and the other to allow the metal to run into moulds. These are channels made in the sand in front of the furnace. The centre, or large channel, is called a "sow," and it passes in a straight line direct from the furnace. The smaller channels are termed "pigs," and they branch laterally right and left from the "sow." At the proper moment the furnace is tapped, and the molten metal flows into and fills these channels. The effect, as a "scene," is one that no person can describe, nor painter do justice to, especially if viewed in the dark. The light direct from the metal is vividly white; and, added to this, are the brilliant coruscations produced by a partial combustion of the metal as it arrives in the open air. It is indeed a sight that, once seen, can never be forgotten, more especially as the "surroundings" of iron-smelting are generally of the most sombre and gloomy, not to say awe-striking character at night, antecedent to the tapping of the furnace. At that instant, however, the gloom is dissipated, and the effulgence of light is so great that none but the "hardened" eyes of those used to it can bear its effects.

Extensive iron-works, seen at a distance at night, have also a singular effect on the surrounding country. The works of Messrs. Baird, at Gartsherrie, near Glasgow, and the most extensive in Scotland, shed a lurid light, that may be seen, by its reflection in the clouds, for miles in all directions. In the Black Country, north of Birmingham, in Staffordshire, from the number of furnaces in constant operation, this effect is especially noticed as general throughout the district. Some idea of the amount of light thus reflected around, may be guessed by those who have not visited an iron-smelting district, if we state that, at Airdrie, three miles from Gartsherrie, the time, as indicated by an ordinary watch, may easily be observed on its dial at night, owing to the reflection of the light from those works.

The derivation of the word "pig-iron" is, from the term pig, applied to the small channels receiving the melted metal, as just described. The pigs are broken off from the sow, and are generally about three feet long, and four inches thick. In this condition the iron is exceedingly impure and brittle; indeed, unfit for any of the purposes to which it is afterwards to be applied, except for very coarse castings; but even for this purpose it is usually re-melted in the foundry, after a manner we shall subsequently explain.

Beneath, but adjacent to the vicinity of iron-smelting-works, the operation of getting the ore is carried on. It in no way practically differs from the method of coal-mining already described, from the sinking of the shaft to the raising of the ore, in any very important particulars. In many districts, indeed, from the adjacency of the coal and ironstone in beds, the two operations are carried on simultaneously; and this is constantly the case in the black band district of Scotland. The general system of coal-mining has been already explained, in all its details, at p. 8, *et seq.*

External to the iron-works, on the surface of the ground, the operation of roasting is carried on, the object of which is to drive off, as much as possible, all volatile matter. Some ores require the aid of small coal, which is laid in alternate layers with the ore, and set on fire. The black band of Scotland has generally sufficient carbonaceous matter, as a part constituent, to permit of a nearly spontaneous roasting after being first ignited.

There are certain technical terms employed by the workmen, which may here be explained, although we shall but rarely use them in this work.

In the mine itself, according to the nature or position of the seam, it receives such names as stripe, nodule, whetstone, wallis, kittle, green meadow, black, blue, cement, old man, tan-yard, &c.—terms the signification of which is perfectly understood by the men, but which it is impossible adequately to convey to our readers. When the ore is brought to the surface it is called raw-mine or green-mine, which is easily understood to convey the idea that the ore is just fresh raised from the pit, and has undergone no process whatever. The term "mine" is used by them in a very different sense to what we have employed it. It is a general designation of the ore as raised from the pit. Thus whilst the unroasted ore is called green or raw-mine, that which has been roasted in the manner already explained, is called "burnt-mine."

We shall continue our general view of the process of the manufacture of malleable iron from the ore, by now following the pig in its various processes, omitting any notice of the Bessemer method until we enter into full details of each of the processes involved in the entire operation described, and yet to be glanced at.

The pig-iron contains many impurities, that cause its want of tenacity. If broken, it appears in granular or crystalline masses, generally of a whitish appearance; and, indeed, in this condition is nearly as brittle as glass. Although, in

this state, it is available for making large castings (a method rarely followed, however, except in special cases, where tenacity is of little object), it is useless for all purposes to which bar, rod, sheet, and other forms of iron are applied. The cause of this brittleness is, to a great extent, to be traced to the presence of carbon, which, by the Bessemer process, is speedily got rid of, as we shall subsequently discover; but by the old method, now to be described, requires long, tedious, and laborious operations.

Two processes are especially necessary to convert the raw pig-iron into the malleable material. The first is that of *refining;* and this is followed by *puddling.* A furnace is constructed specially for the refining process. It has a hearth of fire-bricks, with cast-iron sides that are hollow, so as to allow a stream of water to pass through them, and thus keep down their temperature. At the sides of the furnace are doors, by which the pig and fuel are thrown in, and a powerful draught is caused by a chimney over-head. The pigs are first introduced, and then on them coke and slag are placed. By means of an air-blast, similar in principle to that already described in connection with the smelting furnace, a powerful current of air is driven in, and the heat raised until the pig-iron is melted. The molten metal is then run out into moulds, and cold water cast over it; the sudden cooling thus effected tends to render the metal very brittle, and easily broken up into fragments for the next operation.

This is called puddling; and to carry on the operation a reverberating furnace is employed. The construction of this is such that the flame arising from the burning fuel can be cast down, or reflected by an arched roof, on the metal placed beneath it. The annexed cut exhibits a section of one of these; but it must be stated

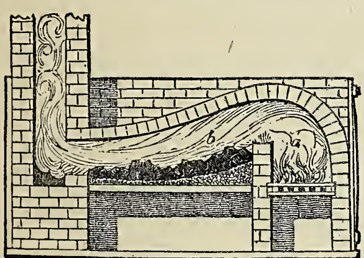


Fig. 94.—Reverberating Furnace.

that the shape is subject to several modifications, constantly introduced, and often the subject of fresh patents. Fig. 94, however, represents the principle of them completely; *a* is the firegrate, and *b* the flame reverberating on the metal.

Among numerous inventions that have recently been made, we may notice the Danks puddling furnace. In this the boilers are revolving, while the method of heating is much similar to the old system. The heat in Danks furnace strikes the top of the boiler and is forced downward by the use of a damper. When the top bars have been melted, the furnace is revolved, and the process is repeated. And when ready to be drawn, the iron goes up one side of the furnace and down on the other, thus doubling over into a ball-like shape, when it is ready to be removed by a fork, transported on a railway to the squeezers, and converted into blooms, bars, &c. One great point about the iron made in the Danks furnace is its chemical purity. In a number of tests made by Mr. Brenlinger, engineer of the Point Bridge, some remarkable results were obtained with this iron It is marvellously ductile, and on one occasion when Professor Langley, in conducting a series of experiments, secured a sheet of iron made in the Danks furnace, he measured it, out of curiosity, to determine its thickness, and found that it would run 10,000 to the inch.

The iron, as obtained from the refining furnace, being broken into fragments, is spread on the hearth, and the flame of the fuel is caused to impinge upon it. As the iron melts, the puddler, by means of a long bar, inserted at the front of the furnace, constantly stirs up the material, so as to equalise the action of the flame until the whole is melted. By constant stirring after this is effected the melted mass becomes pasty, owing to a loss of carbon that is essential to its fluidity, and which, uniting with the oxygen of the air, passes off as carbonic acid gas. The iron gradually agglutinates, and loses all tendency to fluidity after the carbonaceous matter has thus been burnt or oxidised away.

As soon as the puddler judges this result to have been accomplished, his next duty is to convert the mass into separate balls, called blooms, each averaging about sixty pounds in weight—an operation not only exceedingly laborious, but requiring much skill and experience to perform properly. The ball completed, and glowing hot, is instantly conveyed to another part of the works, to be beaten by the shingling hammer. This consists of a long lever, at the end, furthest from the fulcrum, of which a mass of iron is fixed; the whole weighing some tons. The bloom, being placed on a kind of seat or anvil, is now repeatedly struck several times a minute by the hammer, which is itself lifted up by the action of teeth or projections, that raise it by the action of a powerful steam-engine. As soon as the tooth escapes from touching the end of the shorter portion of the hammer extending from the fulcrum, the hammer end falls with immense force or momentum on the bloom, completely flattening it. The bloom is continually turned round, so as to expose all parts to the action of the hammer; and, eventually, attains an oblong form. By this hammering process many solid impurities are actually driven out of the iron.

The next step is to transfer this bar to the puddle-rollers, by which it is greatly increased in length. The mode of rolling the bar is illustrated in the cut (Fig. 95). The bar, still red-hot, is passed between rollers by one workman; and, as it passes through, is caught hold of by a pair of tongs by another man. When it has entirely passed through towards the

latter, he returns it to the rollers, and it as quickly returns to the other side. The operation is repeated until the bar has been nar-

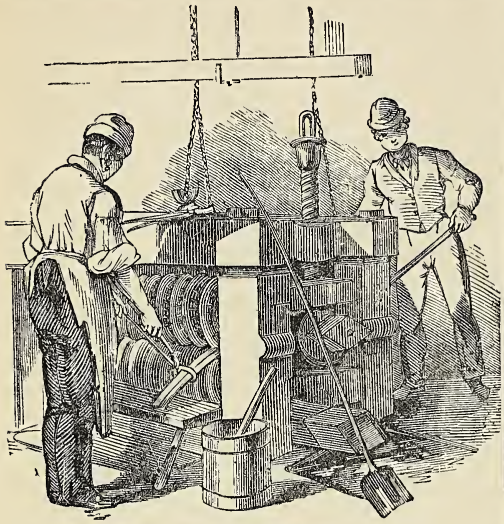


Fig. 95.—Rolling Bar Iron.

rowed to about two or three inches wide, but lengthened to the extent of nearly ten feet. If it cool during the process it must be re-heated.

The change effected in the constitution of the iron is now manifest; for as the workmen complete a bar, they throw it on the floor, where, as it falls, it appears as supple as a bar of lead, readily bending into any form. The iron has therefore lost most of its brittle character, and become very soft, malleable, ductile, because tenacious. It requires, however, further working to render it more completely characterised by these qualities. And in the next process, the property of welding that iron possesses is called into operation (see remarks on welding already given). The bars produced are cut into smaller pieces, collected in parcels of five or six, and introduced in what is called a balling-furnace, there to be raised to a heat sufficient to permit of welding. They are then removed, and passed through another set of rollers, by which each piece in the parcel becomes incorporated with, or welded to the other. By this method the iron becomes of much greater tenacity, the good quality of each bar collectively adding to the tenacity of the whole.

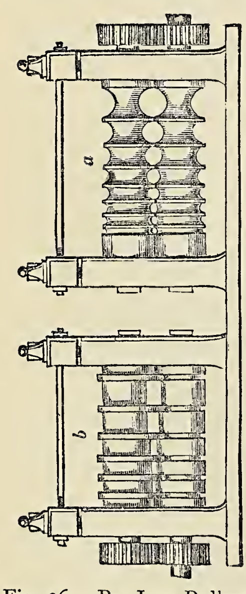


Fig. 96.—Bar Iron Rollers.

By this last operation a proper shape is given to the bars. Thus if passed through the roller *a* in the preceding cut (Fig. 96), they assume a circular form, affording rod-iron; if through the roller *b*, they are produced in a flat or bar form; and, in fact, by making grooves in these rollers, of any desired form, the bar may be readily made to take it. An instance of this is seen in the ordinary rail for use on railways, that is thus grooved, or shaped, during this part of its manufacturing process.

Such is an outline of the old method of producing malleable iron (the rolling, &c., to shape the bars, is, of course, still retained in the Bessemer process). The interior of a puddling work is by no means inviting, for the noise of the shingling hammer when at work is fearful. At some works near Coatbridge, in Scotland, that we have had in our mind's eye whilst penning the previous description, and which has indeed afforded its details, the vibration produced by the hammer is so great, that we have felt the ground shake under the feet in the roadway seventy or eighty feet off.

By the brief description that we have given of the method of converting iron ore into malleable iron, it will be perceived that the series of processes involve many important laws of chemical science. In the first place, we have the ore in its crude or raw state, by no means uniform in quality or constitution. The iron is united, in all cases, primarily with oxygen, in respect to most of the ores employed, being either in a state of protoxide or sesquioxide. Very frequently the protoxide is united with carbonic acid, forming a carbonate of the metal, especially as found in the Cleveland districts of this country; and in those circumstances, as we shall hereafter more particularly notice, an additional cause of difficulty in its reduction occurs. But besides what we may call the legitimate combinations of iron with other substances, such as we have just referred to, external and abnormal impurities are present in most ores—as alumina, silex or flinty matter, magnesia, lime, sulphur, phosphorus, &c. All these must be carefully removed before a really good, soft, ductile, malleable, and tenacious or fibrous iron can be produced—the last condition being indicative of the perfection of the iron; for the nearer it approaches to a crystalline condition, the more is its quality deteriorated.

We have stated that the processes of refining and puddling tend to free the iron from a certain amount of constituent carbon or charcoal matter; but there seems great question as to the truth of this theory, although it is universally accepted as true. One chief objection to it lies in the fact, that whilst we are certain wrought or malleable iron contains much less carbon than cast-iron, and that the abstraction of the carbon effects a striking difference in the chemical and mechanical properties of the iron—cast or carbon iron being brittle, and therefore neither malleable, ductile, nor tenacious—yet, in making steel, we have first to render the iron as pure from carbon as possible; and subsequently it is required to add carbon, &c., to it. This is an

anomaly, at present utterly inexplicable. It is true that a minute amount of nitrogen evidently affects and improves the character of steel, as does also the addition of a small proportion of manganese. Still if we submit steel to careful chemical analysis, we can detect no essential difference between pure iron and steel, characteristically, except in the larger amount of carbon present in the steel than in the pure iron. Yet steel, with the addition of carbon, is more elastic, ductile, and otherwise tractable than iron in its best condition. But we must here refrain from entering into further discussion on a subject not only involved in great difficulty, and one that has puzzled, for the solution of its problem, some of the most experienced chemists and practical men, but that cannot be understood by any of our unpractical readers, who have not, of course, at present, so far as our pages are concerned, sufficient data on which to found any opinions consistent or not with known facts.

Before we enter into a scientific disquisition on the manufacture of iron, of which the preceding account has been given, that our readers may be prepared to follow all the minute details of the process it may be interesting if we give some idea of the methods adopted at the present day, or very recently, in countries where our improved processes are unknown. They will illustrate, to a large extent, the methods that must have been, at former times, adopted in ancient countries; and will, therefore, serve to connect the past with the present of the iron manufacture. It need hardly be remarked, that in the absence of sound chemical knowledge, the processes are crude compared with those now adopted in this and other countries; at the same time, it must be confessed that, in many respects, the iron, like the cotton manufacture, results in the production of far more refined materials in those places where science is unknown, and where blind experience alone guides, than in the best districts of our own or foreign European countries. The Dacca muslin of India, like the Damascus blades for swords, has never yet been equalled, despite all our science and art. For our purpose we shall select extracts from an able paper, published a few years ago, by Mr. Robertson, at that time director of the Shah's ordnance-works in Persia; and from another paper, published in 1867, in reference to the manufacture of iron in India.

The account in reference to the mining and metallurgical processes of Persia, relates to the mines at Caradogh, near Tabreez. The author of the paper remarks, that whilst the early history of the iron manufacture is wrapped in much obscurity, still it is evident that the processes have been carried on from remote ages to the present day, as the iron mines bear evidence of great antiquity. "They form large quarry-like excavations, thickly surrounded by immense tumuli of iron-sand [we may especially call attention to this fact as connected with our further remarks on iron production in India], with small pieces of ore thrown out in the course of working." From certain calculations, partly based on fact, but equally speculative, the writer assumes that these mines have been worked for a period of three thousand years. It seems that Persia imports much iron from Russia; but the native smiths prefer their own, which is very soft, but tough. "It is much superior to Russian iron, with which the greater part of Asia is now supplied, and is manufactured chiefly into horse-shoes and horse-nails, for which there is a great demand in Tabreez and the surrounding districts, and among the Kurds, or nomadic tribes, who frequent the mountain passes in summer." * * * "It (the trade) gives employment to a considerable part of the population in quarrying the ore, burning the charcoal, and transporting these articles to the forge." There are several mines of this ore; the Jewant, Koordkandy, and Marzooly ores being held in the highest commercial value in respect to their production of quality and quantity. The Jewant mine affords red iron ore from the vein, which is of great size, and interspersed with iron-sand. The Koordkandy affords magnetic iron ore, similarly to that already described at p. 53, *ante*; and the product of the Marzooly mine is of a similar character. The vein of the latter is, in some instances, 100 feet thick.

"In working these mines, the richest pieces only of the ore are carried away; the remainder is thrown aside." This may be taken as evidence of the crude method of working, as also seen in the example of our Cornwall miners, who threw away all the copper ore as poder, that we have already stated at p. 1, *ante*. "They (the mines) are worked very irregularly, and without concert, as there is no restriction imposed as to the mode of mining by the government. A few individuals sink a shaft through the rubbish, and excavate as much as they require; another party soon arrive, and fill the first hollow up in the course of sinking another shaft; and in this way the rubbish is repeatedly turned over; but, gradually subsiding, becomes consolidated into a mass as the ore is removed from beneath, thus forming a serious obstacle to any one who might attempt to work the vein in a more regular manner. The ore is carried to the villages only in the summer, as the depth of snow in winter renders the mountain path impassable. * * * *

"The ores above described, when smelted singly, produce that kind of iron which, by English workmen, is called *hot-short*; and by the Persians, *salt-iron*. The smiths, however, by means of a mixture, produce iron of an excellent quality, which they term *sweet-iron*. The most common mixture is two parts of Jewant ore to one of Koordkandy, and two of the latter to one of Marzooly.

"Materials for smelting the ore are found in an extensive forest, which occupies the central parts of the district of Caradogh. The forest covers the flat bottoms between the mountains, and spreads to a considerable height up their sheltered sides, dwindling into dwarf trees and bushes in the more elevated and exposed situations. It consists chiefly of coppice oak, which

springs from the roots of trees cut and re-cut during a long succession of years. This jungle is partitioned among the villages situated on its confines, the inhabitants of which earn a livelihood by supplying the city of Tabreez and adjoining towns with fuel.

"The charcoal is made in the following manner:—A rectangular hollow is dug in the earth, about twelve feet long, six feet wide, and four deep. The sides are formed of the natural ground, a common alluvial level; a small sloping doorway is cut at one end, and at the other a chimney is built, rising to the height of about six feet. The pit is filled up to the level of the ground with cut branches, in all dimensions, placed horizontally and lengthways in the hollow; and they are covered over with earth, and secured effectually against the admission of air, except by a small hole in the built-up doorway, which is left open to produce a current; the heap is kindled through the small opening in the doorway; and after it has burned two or three days the covering is removed, and the charcoal thus produced is stored for sale. * * * *

"The charcoal thus produced, however, is seldom used in the manufacture of iron, the smiths preferring that prepared in the following manner:—The cut branches are merely laid horizontally on the surface of the ground, and piled to a considerable height: having been lighted from beneath, they are allowed to burn in the manner of an open fire till the smoke and flame have nearly ceased; the fire is then quenched with water, when there remains a charcoal which is very light, and is found to reduce the ores of iron in a much less time than the heavier charcoal, produced by the first-named method.

"As the iron is manufactured on a very small scale, a very simple forge answers the purpose. It consists merely of a hollow hearth, dug out of the clay floor of the hut, about fourteen inches square at the bottom, and nine inches deep, for receiving the ore and fuel; and of another hearth immediately thereto adjoining, intended to receive the slag, and consisting of a larger excavation, about three inches deeper than the former, and situated between it and the wall at the other extremity, in which the chimney is constructed. A wall is built on each of the two sides, two or three feet high; and the whole is covered with large stones capable of resisting the action of the fire. The whole of the first or iron hearth, into which the blast is introduced, is left open above and at the sides; but a low wall is built next the bellows (that much resemble those used by the smiths in our country), to prevent the heat from injuring them. The whole is afterwards plastered over with clay and chopped straw, in order to maintain the draught of the chimney entire. The latter is carried up through the walls of the hut, and seldom rises higher than the roof." The construction of the furnace thus described much resembles that already illustrated in connection with the process of puddling, at p. 67, Fig. 94, *ante*.

The method of smelting is thus conducted:—

"The operator having carefully selected charcoal of a small size and light weight, proceeds to clear it from dust and sand with a small meshed riddle, removing all the heavy pieces of charcoal or stones that may be accidentally present. The raw ore being next selected and mixed, and broken into pieces of about the size of a hazel-nut, is thoroughly moistened with water. A dam is then made between the iron and slag hearths, composed of charcoal and charcoal dust well rammed down, and the top is coped with iron slag from a former smelting. The tuyere pipe [see *ante*, p. 64], which is made of white clay, and bears a violent heat for a long time without melting, is then inserted through the small hole in the side wall of the first iron hearth. The point of the pipe is made to reach half-way across the iron hearth, and within six inches of the bottom. A layer of charcoal, three inches thick, is then spread over the bottom of the iron hearth, and upon this two other layers are laid across—one directly under the tuyere pipe, of about six inches in breadth, and three inches deep, and the other at the front of the hearth, of the same thickness, to correspond with the overlying part of the dam. The two trenches which are thus formed are filled with the moistened ore, well rammed down. A second layer of charcoal, in a state of ignition, is thereafter laid over the former under the tuyere pipe; and other successive layers of charcoal and ore are filled in, corresponding with those in the bottom. When the hearth has been nearly filled up in this way, a covering of charcoal is spread over the surface of the whole, on a level with the top of the dam. The bellows are then blown, and a workman, who stands at the side of the hearth, keeps constantly pushing down the charcoal in the middle with an iron rod, and from time to time throws small quantities into the centre of the fire, as it gradually subsides. At the commencement one man at a time is sufficient to blow the bellows; but towards the close two are required, the one standing behind the other. * * * * After blowing for an hour or an hour and a-half, part of the tuyere pipe having melted from the violence of the heat, the blast is stopped for a moment, for the purpose of pushing the tuyere pipe further in towards the centre of the hearth. It is then again continued; and in about three hours, or three hours and a-half from the commencement, the ore becomes consolidated, but not fused. The blast is then again stopped until that half of the bloom [see *ante*, p. 67] which is next to the slag hearth is turned over with an iron bar, and pushed on the top of the dam, while the other half is turned round to the centre of the fire. The blast is then immediately recommenced, and the metal of the half-bloom in the centre of the fire speedily falls to the bottom. The remaining half of the bloom is then drawn into the centre, and treated in a similar manner, very little charcoal being placed on the top of the fire during this part of the process. When the metal has entirely disappeared by sinking to the bottom of the hearth, the whole semi-fluid mass is stirred about for a quarter of an hour longer with an iron rod. The blast being then stopped, the tuyere pipe is

withdrawn, and the operator, taking his shovel, pushes the burning charcoal, together with the dam, into the lower hearth; the slag immediately runs off, and exposes the glowing iron lying in the bottom of the upper hearth: the metal is then beaten with the back of the shovel into a more solid state; and, after being dexterously cut with an iron chisel bar from the sides of the hearth, and forced from the bottom, it is removed to the floor of the hut with a large pair of tongs. The iron is next beaten with large hammers as it lies on the ground, in order to expel the slag and other impurities from its pores; and after being in this way formed into a rough mass, it is lifted to the anvil, where it is again hammered until it attains a more regular shape. It is next cut into two pieces with large wedge-shaped hammers, and is then fit for being drawn into bars of the dimensions required."

A perusal of the preceding account shows that, although the Persian process is, comparatively, in its details of a very simple character, still its results, doubtless, acquired by long experience and practice, and entirely apart from scientific induction, are of a very valuable character. At one operation, smelting, refining, and puddling are performed, and a metal of a very superior quality produced. Compared with the methods (excepting Bessemer's) now universally adopted in this and other European countries, it is far more productive in quantity, and yields a much purer, softer, and tougher metal. This is, doubtless, in a large measure, owing to the purity and richness of the ore; to an absence of many mineral substances constantly present in our ores, and particularly alluded to at p. 54, *ante;* and, lastly, to the use of charcoal as fuel. Indeed, the simplicity of the method also, without doubt, influences the result; and we agree with the writer just quoted, when he remarks—"The rich iron ores of Cumberland and Lancashire, and many others in Great Britain, particularly the black-band ironstone (see *ante*, p. 52) of Scotland, if manufactured in the same manner, would, undoubtedly, produce similar results, and thus create a great saving in time, labour, and capital, as well as diminish the cost of materials." We must bear in mind, however, that the great feature of our iron production is not so much the quality as quantity; and whilst one smith and his assistants make 1 cwt. by three or four smeltings, after the manner just described, our smelting furnaces turn off tons daily of pig-iron, at infinitely less comparative cost, although of a much more impure character.

The ancient Egyptian method much resembled that now described; and, at the present time, in many parts of Asia Minor, iron ores, very rich in their character, are similarly treated. A cupola furnace, and a fuel of dry wood, are substituted for such as we have mentioned as used in Persia.

The following account, extracted, or rather selected from the eminent engineering journal already once quoted, will be read with interest, as presenting many parallel circumstances with the Persian method, just described.

The extent of our Indian empire is such that all mineral productions might naturally be expected to be yielded in great abundance. Yet, although iron is required in that country to an enormous extent, especially since the introduction of the railway and telegraphic systems, the native production is too insignificant to supply anything like the demand, which is accordingly met by export from Great Britain, causing, by expense of transit, interest, insurance, &c., a great increase on the price at which it is purchased in this country.

One circumstance much influences the amount of production in India; and that is, the absence of fuel and limestone, so essential for the abundant smelting of iron. Indeed, the Indian ores, in many cases, are similarly situated to our own in Northamptonshire; that is, far from coal, &c.; but much further in the Indian case than in our own, which can readily be overcome by us through a few hours' transit of the ore from Northamptonshire, &c., to Staffordshire, as already mentioned at p. 53, *ante*. On this and other points, however, we shall avail ourselves of the following article on the manufacture of iron in India.

"In the neighbourhood of Magadi, in Mysore, iron is procured partly from the black sand, which is found, in the rainy seasons, in the channels of all the torrents of the country, and partly from an ore which is found at Ghettipura, about seven miles from Magadi. Much steel was formerly made at Ghettipura, from whence it derives its name, which signifies, literally, 'hard town:' near it are many cultivated fields, intermixed with low rocky hills, in both of which situations the ore is found. The iron ore in the fields consists of small irregular masses, separated by thin layers of earthy matter, and is found in beds from five to ten feet deep; and, in places, they come so near to the surface as to be disturbed by the plough. In the hills the ore is also found by digging a very little depth into the soil, and seems to be the source whence most of the black sand of the country is washed by the rain. On the surface of the hills is also found another iron ore, which is scattered among the gravel in small lumps, from the size of an egg downwards; they are a purer ore, and are put into the furnace without any preparation, except breaking the larger pieces into bits of about the size of a filbert.

"About ninety miles to the north-east of Seringapatam, iron is smelted at various places in the following districts—viz., Madhugiri, Chinnarayan-durga, Hagalawadi, and Devarayadurga. In the first two districts the iron is chiefly made from the black sand, which the small torrents, formed in the rainy seasons, bring down from the rocks. In the two latter districts it is made from an ore found on the hills.

"Crossing the Cauvery, and to the south-west of Mysore, on the north side of Chica Deva Belta, are three low hills, which produce iron ore. The strata are from one to three feet in thickness, and consist of granular quartz, more or less impregnated with iron ore, which is of

the same nature with the common iron-sand of the country. In most of the strata the quartz predominates ; and, by the natives, these ores are considered useless; in others, although having nearly the same appearance externally, the iron is more abundant.

"In most of the streams throughout Coimbatore iron-sand is found ; and, in some channels, the ore appears in lumps about the size of peas. In a great many of the villages iron is smelted from this sand.

"In Malabar, the usual black sand is found mixed with clay in strata near the river, in the neighbourhood of Colangodu ; whilst at Velater and Walachery, iron ore is found in all the hills, forming beds, veins, or detached masses in a stratum of indurated clay. The ore is composed of clay, quartz in the form of sand, and of the common black iron-sand : the mixture forms small angular nodules closely compacted ; and they are very friable. The ore is dug out with the pickaxe, and broken into powder with the same instrument.

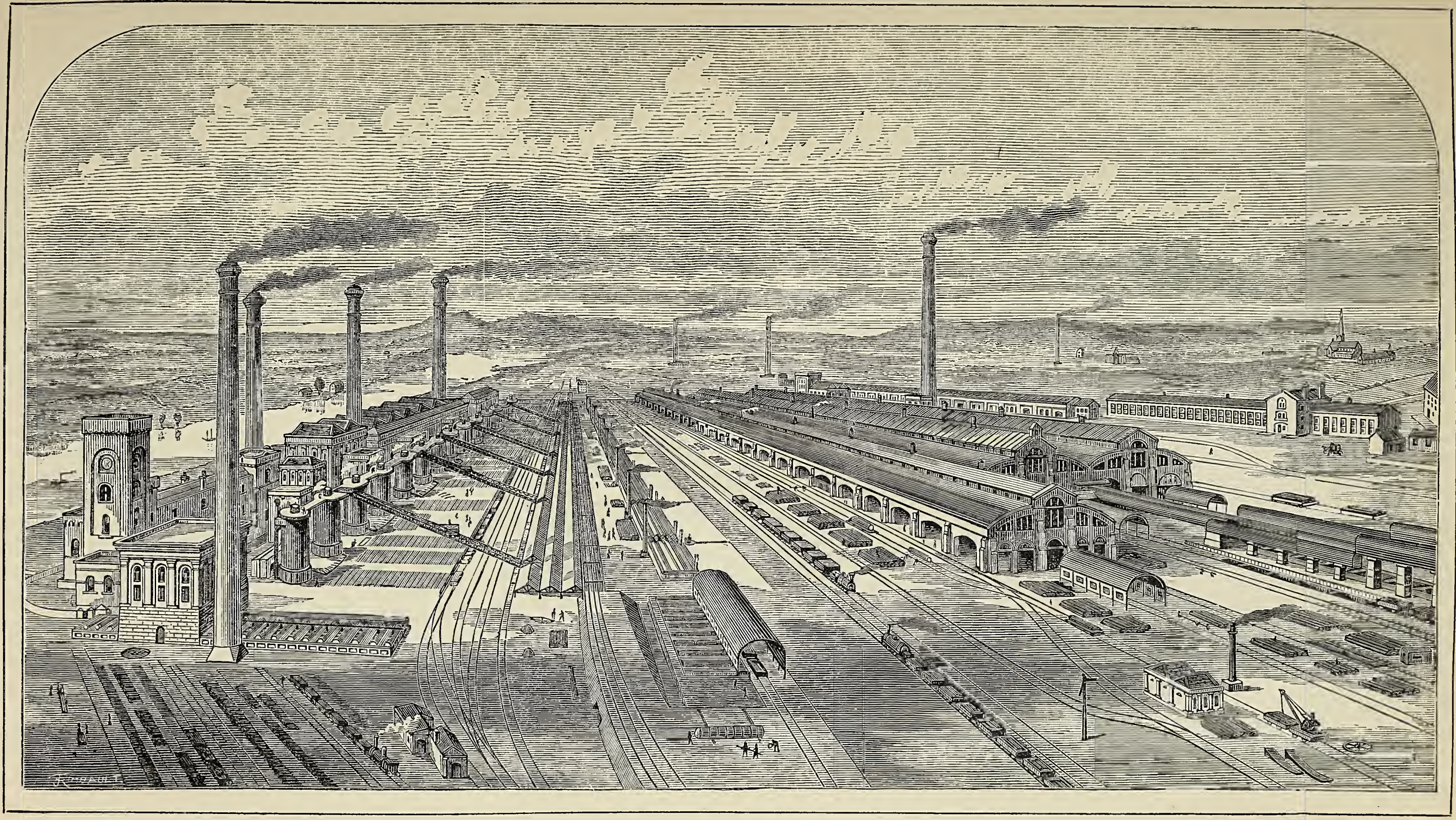
"Turning now to the north-west of Mysore and Chandra-gupti, is a hill producing iron ore, which is of the same nature with that usually smelted in the peninsula (of India) ; that is to say, it is a black-sand ore, which here is agglutinated by clay into a mass, and contains less extraneous matter than usual ; it is broken into small pieces, and the little masses of iron are picked out of the clay. It is stated that, in Billighy and Sudha, there is abundance of ore ; but, in those districts, there are no people who understand the process (of smelting).

"At Ellady-Caray, iron was formerly smelted from the black sand, which was brought from a hill about two miles to the westward ; but the work has been abandoned for many years, owing, it is supposed, to the want of fuel in that neighbourhood. Iron ore is also found in a mine called Cudera Canavay, near Chica-Baylicaray, which exists in small slaty fragments. These are broken to pieces with a stone, and then separated from much sand and earth. The small pieces, when fit for the furnace, are about the size of a hazel-nut.

"In addition to the above-mentioned places, iron ore is also found at Cari-Cullu (which means 'black-stone'), where it is picked up on the surface in lumps of about the size of the fist, and has a very strong resemblance to the black ore of manganese ; at Doda-Rashy-Guda, or great-heap-hill, where the ore is the same with the black kind at Cudera Canavay, but is imbedded in large irregular cavities of the barren stone. Near Chenapatam and Rama-Giri are the mines whence Seringapatam receives its chief supply ; and in the woods near Tully is found some black-sand ore, which is smelted into iron.

"The process of manufacturing iron differs somewhat in the various districts ; but one illustration of the native method will suffice to give some idea of the rude appliances adopted in so important a manufacture. The following description applies to the neighbourhood of Magadi, in Mysore, where the iron is made partly from the black sand, which is found, in the rainy season, in the channels of all the torrents in the country, and partly from an ore which is found in the neighbourhood. During the four months of heavy rains, four men are able to collect as much sand as a furnace can melt in the remainder of the year. The smelting furnace is made in the front of a square mound of clay, sloping up gradually from behind. In the front, the mound is twenty-two inches high, and three feet broad ; and in this, from top to bottom, is made a semicircular cavity, about a foot in diameter. On the ground, in front of the cavity, is laid a stone six inches high and one foot square ; in front of this is placed another stone, one foot square and two inches thick, standing on end ; and on the top is placed a small piece of timber, behind which rises another mound of clay, sloping upwards gradually, and widening as it recedes from the furnace. On this rests the bellows, of which there are two, each consisting of a whole buffalo hide, removed without cutting it lengthwise ; where it has been cut at the neck it is sewn up, so as to leave a small opening for a wooden nozzle, which is made fast to the piece of timber before mentioned ; the hinder part of the skin is slit vertically, and the one side is made to lie over the other : in the middle of this outer side is fastened a ring of leather, through which the workman passes his arm, and seizes the upper angle of the skin, which serves as a handle ; and by drawing it backwards and forwards, he forces a current of air through the nozzle. The lower part of the bellows is retained in its place by a rope, fastened to the lower angle, and supported by an elastic piece of timber, which is fastened to one of the posts of the hut. The nozzles of both the bellows are inserted in one common tube, which is made of baked clay, and is placed in a sloping direction, so as to pass through a mass of moist clay that occupies the front of the furnace above the first-mentioned stone. Above this is placed a large tile, and the empty spaces between this and the mound are filled with moist clay. The furnace is now cylindrical and open at the top, on which is placed a chimney, made of baked clay, in the form of two truncated cones, joined together by the apices (or pointed ends). It must be observed that the whole lower front of the furnace is movable ; and when it has been newly built up, a little charcoal is burned in it for an hour, to dry the moist clay by which the various parts are connected. * * * *

"For smelting the black sand, the following is the process :—A quantity of the sand is measured out, and divided into three parts, each weighing about twenty-six pounds ; three baskets of charcoal are then set aside, each of which contains a bushel. Two of the baskets of charcoal are then put in by the top of the chimney, and, above these, one part of the black sand is introduced. The fire is then kindled, and urged by the bellows. When the fire subsides, one-half of the remaining charcoal, and another third of the black sand, are put in. When these have subsided [sunk down we presume], the re-



THE BARROW HEMATITE IRON AND STEEL WORKS.

mainder of the charcoal and black sand is added, and the fire urged until six hours and a-half have elapsed from the commencement of the process. The front of the furnace is then broken; and on removing the walls, a mass of iron is found at the bottom, which is taken out with tongs, and cut into two blocks, weighing each a little more than twelve pounds; so that the ore yields about 31½ per cent. of metal. The iron so produced, although malleable at first, is extremely impure. Tippoo used to take it from the workmen at 9*s.* 3½*d.* per hundred-weight; and he gave great employment to the iron manufactures, as he made his shot of this iron by hammering, for the fusion was never so complete as to allow it to be cast into moulds.

"The operation for smelting the ore is exactly the same as that used for the black sand, except in regard to cleaning it. The ore is first reduced to powder by an iron bar, and then the earthy particles are washed away in a wooden trough, when it becomes exactly like the black sand, and is called by the same name—'adura.' The collecting of it is attended with less trouble than that employed to gather the black sand; but the difficulty and expense of carriage to any considerable distance prevents it from being generally used."

The perusal of the two preceding accounts that we have quoted, somewhat in a modified condition, in respect to the production of iron in Persia and India, at places many hundreds of miles apart, and connected by no means of communication in the least degree practicable, will show how much the force of custom influences ignorance in the pursuit of an art, and yet how great perfection may be arrived at, apart from scientific teaching. The methods that have been described have doubtless been followed for ages, perhaps from the earliest date at which iron was produced from the ore. It is evident, however, that if the ores described were not exceedingly rich, or required the agency of aluminous or lime fluxes, the methods described would have been impracticable. In both instances we notice that the workers in Persia and India choose only the richest ore, and which is almost entirely composed of the oxide of iron, and consequently characterised by an absence of earthy impurities.

We now return to consider some details of smelting and other processes, a general view of which has been given at p. 64, *ante*, and subsequent pages.

First in order, we must notice that ores require very different treatment in many respects, but especially as regards the flux employed for their reduction. An excess of lime in an ore indicates the necessity of an addition of clay; and, *vice versâ*, an excess of clay equally requires an addition of limestone as a flux. Lime and aluminous matter have a great attraction for each other at a high temperature, and mutually act as fluxes. Thus an argillaceous or clay iron ore will usually require limestone as a flux; and this is generally the condition of the mass of ores smelted in Great Britain; hence the great value we have already stated to be involved in the superposition of ore, limestone, and coal, in many districts of our island. Two extreme cases may be taken, in which the opposition of flux to chemical earth constituents are found—the one in the lime-ironstone of the Forest of Dean, which requires clay as a flux; and the Derbyshire ironstone, that, containing clay, requires lime as a flux for smelting it.

By an ingenious adjustment of chemical affinities and properties, the smelter, if the cost of carriage does not interfere, may, to a certain extent, regulate the requirements of different ores by their judicious admixture. It is evident, for example, that a clay-ironstone and a lime-ironstone may be so nearly used in their natural proportions as to produce results equivalent to the addition of the separate fluxes during the process of smelting; the excess of clay in the one neutralising the excess of lime in the other. This is now commonly practised; and not only is economy of manufacture the result, but the quality of iron is also improved. For example, the Ulverstone ore is a red hematite, which may be considered as a lime ore. By smelting the argillaceous ore obtained from some parts of Ireland with this, a sufficient quantity of alumina (clay) is obtained. The slag from the process gives upwards of 50 per cent of lime, with about 15 per cent. of alumina, magnesia, &c.

It is thus evident that an intimate knowledge of chemical laws should be one qualification of those engaged in the smelting and other operations connected with the manufacture of iron; yet, as already noticed, experience and custom have frequently more sway in directing those operations than science.

We have already incidentally alluded to the application of the *hot blast*, as first brought forward by Mr. Neilson, about the year 1829; and by which much expense, time, &c., are saved—coal being now, by its employment, used in place of coke. Various forms of ovens or stoves are employed to heat the air, which is frequently raised to a temperature of 800° or 900° Fah. Recently, the waste gases of the smelting furnace, that formerly escaped at its top in a highly heated state, have been much utilised, especially in producing the steam that drives the blowing-engine. About thirty years ago, Mr. Houldsworth, of the Coltness iron-works, near Wishaw, Lanarkshire, Scotland, was one of the first to attempt the utilisation of the enormous amount of heat, formerly wasted from the top of the smelting furnace. He applied it to the purpose of calcining or roasting the ore previous to its being smelted. The method was to withdraw the hot air from the furnace, just below the opening at which the ore is introduced, by means of a ring-like or annular flue, whence it proceeded, by means of pipes, to the calcining kilns, in which the ore was roasted. The draught of a chimney was employed to increase the tractive power of the gas through the ore. Of course, an enormous amount of heat is wasted, after the usual plan, in the smelting of iron; and it therefore can be no matter of surprise that its utilisation has been a question of such importance as to induce numerous in-

ventions, by which it may be applied to useful purposes, rather than being wasted by expulsion into the atmosphere. Of this we shall speak more fully hereafter.

In the blast furnaces at Barrow-in-Furness, the gases are carried off sideways from the furnace-top, near to which is a fire-brick arch, in the centre being a ring, through which the white-hot gases and flame pass, and then proceed horizontally. By such means much of the heat of the smelting furnace is utilised—sufficient, indeed, to create steam in several boilers that supply the blowing and winding (pit) steam-engines. Now here, of course, there must be an enormous saving of fuel; for although coal is cheap enough at the pit's mouth, still it cannot arrive there, nor in the boiler furnace, without the expenditure of much steam or human labour—indeed, both; and, by the arrangement above described, these causes of expense are avoided.

Into the minutiæ of many of the mechanical arrangements of iron-smelting works, we cannot, of course, here enter. In fact, our difficulty lies in condensing the materials that have been gathered from the assistance of friends engaged in the manufacture of iron, and personal experience, only so far as chemistry itself is involved. But both the chemical and mechanical contrivances used in the smelting of iron, are constantly increasing in number and variety; and to keep pace with them would require almost a monthly publication of specification of patents brought out for the purpose just referred to. Many, even of these, require modification to special cases; hence an exposition of even a selection of them would be tedious and incomplete.

As an illustration of the character of some of the higher class of iron and steel works in this country, we give the following description of Barrow Hematite Iron and Steel Works, as seen in 1880, with the alterations that have been made since 1874, for which we are indebted to "Engineering" the account having been written during the visit of the Iron and Steel Institute to Barrow, in July, 1880.

"At these iron works two considerable alterations have been made since 1874. The long row of fourteen blast furnaces has been reduced to twelve, and the changes have been necessitated by the introduction of the 'direct process,' which involves the transportation of the iron molten from the blast furnace direct to the Bessemer converter.

"The four oldest blast furnaces, Nos. 1, 2, 3, and 4, have been entirely pulled down, ana on the ground they occupied two new ones have been built, one of which is not yet in blast. It will be remembered that Nos. 1, 2, and 3 furnaces were much less in height than the remainder, but now the whole twelve are practically on a level, and there is a communicating gallery for the total length. The two new ones are 62 feet in height, with boshes 21½ feet in diameter, and therefore of the same dimensions as the two at the other end of the row, which were the newest in 1874. The hot air apparatus for the two recent furnaces consists of three Whitwell stoves, 50 feet high by 18 feet diameter. All the other furnaces have the ordinary pipe stoves with the exception of two, which are fitted with five Cowper stoves. In addition to the row of twelve furnaces there are two others, at a separate works, about half a mile distant, of the same dimensions as the new ones just described. The whole of the furnaces have close tops on the bell and hopper system.

"To carry out the 'direct process' a siding has been constructed at the iron works in a cutting about 9 feet deep at the base of the line of the pig beds, inside the boundary wall. Into this two or three wagons are shunted at a time; they are of simple design, and especially arranged for the transportation of the molten metal; they each have in the centre a ladle capable of carrying, if necessary, 11 tons or 12 tons of metal, though about 8 tons is the usual quantity. Formerly the ladles were placed at one end of the wagon, and were balanced by weights at the other end; but the new design works better, and is of course much lighter. The metal is run from the furnace the whole length of the pig bed down an ordinary channel in the sand, to a point where there is a movable spout, over which the molten iron falls into the ladle. If desired the whole charge need not be taken from one furnace alone, but a mixture of the products of different furnaces may be made. When sufficient iron is in the ladle the channel is stopped, and the rest of the cast is allowed to run in the usual way for the manufacture of pigs. No difficulty is experienced as to the chilling of the molten metal; a small quantity of coal dust is sprinkled over the top, and the iron arrives at the steel works without any injurious loss of temperature. From the twelve furnaces the molten iron travels about a mile to the steel works, having to run to a junction, but from the two isolated furnaces the distance traversed is nearly two miles, and even in this length of journey no inconvenience has been experienced by the metal becoming cold.

"One of the most interesting discussions at the 1874 meeting of the Iron and Steel Institute was in reference to the practicability of transporting the molten iron from the blast furnace to the Bessemer converter. The system had been even then tried, and had succeeded, on the Continent, but in 1874 it was believed that, at least in England, the process would be too hazardous. Even if the practical mechanical difficulties could be overcome at those works originally designed for the old system, it was considered by most of the steel-makers that it would be impossible to obtain constant results from the blast furnace, and to make steel from iron, the nature of which was unknown, would be too dangerous a leap in the dark. Within the last half-dozen years, and within a mile of the scene of this discussion, the question has been practically settled on a scale of the greatest magnitude. Thirteen of the Barrow furnaces are now in blast, and the yield is over 6,000 tons per week; of this quantity more than a third goes to the steel works, and now none is

in the form of pigs, unless to fulfil some order where reheated iron may have been stipulated. In regular working it is known beforehand what will be the quality of the iron, and there has been no difficulty in this respect. Doubtless the large number of furnaces at Barrow is a great advantage, as if any of them are temporarily not in good working order, the iron for the converters can be obtained equally well from other furnaces. It is quite possible that at small works, with not more than two blast furnaces, more or less serious inconvenience might arise by the temporary derangement of one or both furnaces, which could only be effectually guarded against by heavy stocks of pig iron, and much extra plant in cupolas, &c., which would mean a large amount of capital usually lying idle. Within the last two or three years a considerable quantity of spiegeleisen (see *ante* p. 60), has been made at Barrow, but the manufacture is intermittent, and almost, if not quite, exclusively for the company's own requirements.

"The deposition of slag, to which we referred in our previous article, goes on apace, and a considerable tract of ground has been reclaimed from Walney Channel, and lines of railway may now be seen where the tide flowed six years ago.

"The mineral supply for these works is under very much the same conditions as in 1874. The Barrow Company still remain the largest raisers of iron ore in the district, and their mines yield about 400,000 tons of red hematite annually. The production in Furness of this valuable ore has not materially altered for several years, although individual mines have had fluctuations in fortune. Among the important mines of the district are those of Lindal Moor, the property of Messrs. Harrison, Ainslie, and Co., where, in the immediate neighbourhood, and possibly at the same place, hematite has been worked for 300 years, and the mines are still extremely valuable and productive. This firm are the only makers of charcoal iron in Great Britain; they have three furnaces in the Lake District, one in Hampshire, and one in Argyllshire, all placed for the convenience of the charcoal supply, and only one or two are in blast simultaneously; the quantity of iron made is small, but is of the highest quality. The Park mines of the Barrow Company and the Roanhead mines belonging to Messrs. Kennedy Brothers adjoin, and both are extremely productive; the Park mine has been the richest find in the Furness district. The mines of the Hodbarrow Mining Company politically are in Cumberland, and therefore are not reckoned in Furness, but physically they belong to the district; the deposit is very large, and the quality of the ore is rich even for Cumberland hematite.

"For the Barrow Works the company formerly obtained the whole of their coke from Durham, but latterly a portion of their supply has been derived from their own collieries near Barnsley. The flux used in the furnaces is the mountain limestone of the district, and it is in caverns and fissures of this rock that exist the great masses of red hematite, which were the foundation, and are the mainstay of Barrow.

"Between the iron and steel works an experimental group of Coppée coke ovens has been constructed. This Belgian system of making coke has long been extensively adopted on the Continent, but has not made very great advances in England. When this group of ovens were erected at Barrow very few others were in existence in Great Britain, and none perhaps gave the system a fair trial. It may be presumed that at Barrow the experiment was fairly successful, as the Barrow Company have built several other groups at their Barnsley collieries. The Barrow group consists of thirty ovens, each thirty feet long by eighteen inches wide; the Barnsley groups have been slightly modified in the direction indicated by the practical working at Barrow. By this system, with suitable coal, over 75 per cent. of coke may be obtained in twenty-four hours' working.

"The steel works are parallel to the iron works, but are separated from them by a space partly occupied by the Furness Railway Company, which thus has direct access to the works. In the main features the steel works continue as in 1874, but there are a number of minor changes. The chief alterations are the reduction of the number of converters, the erection of cogging mills, with the consequent removal of some of the hammers, and the recent introduction of the Siemens-Martin process (to be afterwards described). In 1874 there were eighteen Bessemer converters at work, the largest number ever erected at one works. A few years ago the world of steel-makers was astonished by the prodigious output obtained in America from each converter. That far more converters were then used in England, beyond what was necessary, is very significantly proved by the fact that the eighteen converters at Barrow have been reduced to twelve, two of which are never used, and doubtless even less than ten would suffice for the production of the steel, which, by the Bessemer process is from 2,000 tons to 2,500 tons per week. In No. 1 shed, the oldest part of the works, there were four converters; of these two are not used, and we understand they will shortly be dismantled. In No. 2 shed the six converters remain as they were. But in No. 3 shed they are now only two, where formerly there were eight. Raised sidings have been constructed to enable the locomotives, with the molten metal wagons, to proceed direct to the pit hill in both Nos. 1 and 2 sheds, and from the latter there is a communication with the pit hill of No. 3 shed. The wagons are constructed to allow the ladles to be tilted, and the metal is poured down a funnel and runs into the converters. The old iron melting cupolas are practically disused, and most of them have been pulled down, the smaller spiegeleisen cupolas alone remaining.

"In the centre of the works, where the hammers are situated, the number of these has been reduced, as the major portion of the steel is now not hammered, but cogged. The plate mill that formerly existed here has been removed, and the engines drive two cogging mills, the rolls for one being 30 inches, and for the other

36 inches in diameter. With these mills very much larger ingots may be dealt with than when they are hammered. With the latter process the ingots rarely exceeded 13 cwt. or 14 cwt., but now they are cast up to 35 cwt. The cogging mills being nearly automatic there is no difficulty in treating these large blocks, and when the bloom is finished it passes from the finishing rolls by a self-acting set of rollers to a hammer by which it is cut into three or more smaller blooms to sizes that may be required. Near the cogging mills is placed the arrangement for Mr. Alfred Davis's plan for compressing the ingots by steam. The Siemens-Martin process is not as yet in full working at Barrow. Two ten-ton furnaces are in course of construction. Rails are the staple product of these works, but when the Siemens-Martin process is at work, it is intended to carry on the manufacture of steel plates." In the details of machinery for preparing finished iron, it is needless to add that the most recent improvements have been adopted at Barrow.

In 1860, Barrow-in-Furness was but a village; but, in seven years, its population increased nearly tenfold, owing to the establishment of iron-works for the production of pig-iron from the red hematite ore already mentioned as used by the Kirkless Hall Company, in connection with the Wigan Coal and Iron Company. Formerly, all the ore produced in this rich district was sent by sea to Wales, or by railway to Staffordshire, &c., for smelting purposes. At that time the ore was used only to a limited extent, owing to its expense, and chiefly for mixing with other ores, to improve them; and also from the difficulty of smelting the red hematite alone. But, in 1859, the enterprising firm of Schneider, Hannay, and Co., erected some blast furnaces close to the sea-shore, and convenient for obtaining the ore and fuel to smelt it. The chief stimulus to the production of metal from this ore, however, arose from the discovery of the Bessemer process, the influence of which on the entire iron manufacture we have already pointed out as having been so beneficial. Gradually, therefore, Messrs. Schneider added to their works at Barrow, until, from four furnaces in operation in 1860, they had ten in 1866: since then, the Barrow Hematite and Steel Company have taken the business, whose works we have just described. The effect on the increase of population was astonishing, each second year evidencing a doubling or trebling of the inhabitants; and hence, from an almost neglected village, Barrow has become a town of great commercial importance, with a present population of upwards of 25,000 persons, all more or less dependent on the iron-works for their means of subsistence.

But, whilst drawing attention to the details, progress, and the extent of the iron manufacture in our own islands, it would be unjust if we were entirely to omit notice of what may be seen abroad. In Belgium, we may especially call attention to the iron district of Charleroi, Liége, Namur, &c., where iron manufactures are carried on similar to what we observe in South Staffordshire, Wales, Sheffield, and Birmingham, amongst us.

But the most wonderful industrial undertaking, perhaps, in any part of Europe, is that found in Messrs. Schneider's works at Creusot, in France. Le Creusot is in the department of Saone et Loire, and about 250 miles from Paris; being situated over a coal seam in the carboniferous basin. It is favoured by canal, railway, and other efficient means of transit; and has long been identified with the iron trade. The town is owned by Messrs. Schneider, and contains a population of 25,000; of whom 10,000 are employed in the iron-works, which are of the most gigantic description. It was here that Watt's early steam-engine became first introduced to foreign countries; and the first steam hammer, produced by M. Bourdon, then chief engineer of Creusot, gave Nasmyth the initiative of his invention, since so largely adopted and improved on. The extent, perfection, and careful management of this noble concern, enable it to compete successfully with English manufactures in all branches of ironwork; indeed, the firm have contracted for the supply of locomotives for use in this country.

Up to 1826, the works had been far from profitably worked, perhaps chiefly owing to the want of means of transit, without which, as we have seen in the case of our Northamptonshire ore (p. 53, *ante*), the richest mineral districts are temporarily of no value. Falling into the hands of Messrs. Schneider, one of the chief banking firms of Paris, in 1837, the capabilities of the place became gradually developed. The introduction of the railway system, that occurred generally throughout Europe at that period, lent its powerful aid, and four blast furnaces were set to work. By degrees, the area of the works was enlarged, until they have arrived at the position they now occupy. A visit to England by M. Schnieder, in 1846, led to the introduction of the best kinds of machines used by us; and from that day, the motto of the establishment has been, "the absolute determination to arrive at perfection." In Germany, at Essen, M. Krupp's works are of great size.

In America iron-works of great magnitude have been constructed, and the United States are largely supplying themselves with iron, although they still have to draw largely on this country for both pig and the manufactured article.

We have thus described the chief works in England, Scotland, France, &c., and compared, by the facts afforded, the various methods adopted in each for the smelting of iron, the old plan of puddling, rolling, &c. The limits of our work forbid us entering into minute details in respect to the machinery by which the malleable iron is converted into a thousand useful forms, although this is a subject that will be again taken up after a description of the Bessemer process.

The iron manufacture has such extensive ramifications, that no ordinary work can do its details justice. Omitting the consideration of steel, to which we shall presently devote a separate article, following that connected with

the Bessemer process, let us take a rapid glance at the numerous applications of which wrought or malleable iron is the subject. Amongst the largest kind of works to which it is applied, we may notice railway and river bridges, of which such splendid examples are seen in this country, over the Menai Straits, in the Britannia Railway, and the Menai suspension bridges; Westminister, and other iron bridges over the Thames, now so rapidly multiplying; girder bridges, and viaducts on every railway; shafting for factory and steam-ship purposes; wrought-iron plates, for constructing sailing and steam-vessels, in which an enormous quantity of material is annually used; all the machinery in our cotton, wool, flax, and silk mills; the almost endless variety of screw-cutting, planing, drilling, punching, and other metal machinery; bar, rod, and railway-rail iron, &c., &c. In its more restricted use, whether of size or quantity, we may notice roofing for railway and other sheds; tin plate, which is sheet-iron coated with tin; galvanised iron, or the metal coated with zinc; ties and bonds for brick and stone buildings; hoop iron, for cooperage, packing-cases, and similar purposes; domestic utensils of almost every possible variety; iron wire, equally as variously applied; until at last we arrive, through a long list, to the little brad of the carpenter or shoe-maker.

Such a variety is astonishing indeed; and still more so when we remember, that many of these applications of iron have only been made within the last hundred years, whilst most of them have a date of less than fifty years as their origin. We have omitted the consideration of cast-iron objects, although these are extremely numerous; for the process of casting differs from smelting but little in its details, which are entirely of mechanical, and not a chemical, character. The furnace employed for the purpose is on a much smaller scale than that of the smelter, and is usually called a cupola. It is built according to the requirements of the casting-works. The fuel employed is invariably coke; and a blast is communicated to it in a similar manner to that of the smelting furnace. Moulds are made from a wooden pattern in moulders' sand; and these, when removed from the sand, leave a hollow, which the molten metal is intended to occupy. Arranged on the floor of the casting-house, having been previously baked to drive off all possible moisture, the presence of which would cause dangerous explosions, the melted iron is conveyed to them either by a kind of pot or ladle if the work be small, or in great tanks holding several tons, and suspended from cranes that move the pot from the mouth of the furnace, whence it has received its supply of the molten metal, to the mould intended next to receive it. Numerous precautions are required in the choice, &c., of the iron, the construction of the moulds, and many other matters, to obtain a sound casting; that is, one free from flaws or defects of any kind.

Of recent years, the uses of cast-iron have, in some senses, diminished; whilst, in others, they have been increased—the latter being, due to a great extent, to the Bessemer process, which literally and directly converts cast-iron into an almost equivalent, in strength, to the best wrought-iron; and yet, for the purpose now referred to, can be used for castings. But we must not here anticipate the description of this process, a minute account of which will immediately follow. In respect to applications of cast-iron after the old method, many will at once suggest themselves to our readers, for they are familiar in the pots, pans, water-pipes, railings, cast nails, &c., &c., of our houses. Frequently, castings are adopted in bridges, and form mostly a part of machinery. Still, as the tenacity of cast-iron is so much less than wrought iron, the latter has greatly superseded it; and cast-iron, in large masses, can only be safely used when it is subject to little or no vibration. Thus, whilst cast-iron pillars will safely support portions of a building, perhaps for centuries, if the same material were used for railway wheels or axles, at any moment they would be liable to utter destruction for want of tenacity.

The Bessemer Process.

With the exception of an occasional remark on various applications of iron, prepared by the Bessemer process, we have hitherto confined our attention to the ordinary processes of smelting iron from the ore, and the methods of making wrought-iron from the pig thus produced, according to the old system of refining, puddling, and rolling. It will now become our business to describe, perhaps, the most successful invention, and certainly one of the most profitable, that has yet been brought out in any branch of manufacture—an invention not the result of accident or luck, but that has arisen by an enlightened application of pure science to practical purposes, and each step of which has been arrived at, not by hap-hazard, but by careful experiment and induction from facts as they arose during repeated trials. As a man of science, a benefactor of his country, and, indeed, all others where iron is used, Sir. H. Bessemer is entitled to the highest praise; and fortunate is he in having obtained a rich pecuniary harvest —a result not often the luck of ingenious inventors. On this subject we have already made extended remarks at pp. xi and xii in the introductory chapter, where will be found an illustration of the casket presented to Sir H. Bessemer by the Corporation of the City of London, and an account of the incidents that occurred on that occasion.

To understand the nature of the improvement first introduced by Mr. Bessemer in 1856, we must for a moment revert to the description of the refining and puddling processes, already given at p. 67 *ante*; and also describe the ordinary method of making steel, as adopted previously to Sir H. Bessemer's invention, and still remaining largely in use; for, despite the great advantages of the new system, its progress in replacing the older methods has been comparatively slow until recent years. Before pig-

iron is refined and puddled, it contains a considerable, but variable, proportion of carbon, silica, or the oxide of silicium (sometimes called silicon), and that is analogous, in many of its qualities, to carbon, together with various proportions of phosphorus, that make the iron what is called "short" in the technical phraseology of the trade. Sulphur may also be present, and possibly other substances, which, for the present, we may omit notice of.

When the refined pig is put on to the hearth of the puddling furnace, the chief result effected by the flame reflected from the roof of the reverberating furnace, is that of causing the carbon combined with the iron to leave the metal, and attach itself to the oxygen of the air that also has access, and thus carbonic acid and carbonic oxide are formed. Both these are gaseous bodies, and they pass off with the smoke up the chimney. By such means, the carbon, which is the chief cause of fluidity and hardness of cast-iron, is got rid of, and the metal becomes soft, tough, fibrous, malleable, and almost infusible. The difference, therefore between cast and wrought, chiefly consists in the presence of carbon in the former, and its absence to a certain extent in the latter condition of the metal. The reason of the soft nature of iron prepared after the manner adopted in Persia and India (see p. 70, *ante*, and following pages), without the labour of puddling, is evidently due to the richness and purity of the ore, that almost entirely consists of the metal united with oxygen, and forming an oxide, which is readily decomposed by heat and the carbon in the charcoal of the fuel.

It is evident, therefore, that the great object of puddling is to get rid of the carbon in cast-iron. In respect to the other impurities, they are not so easily dealt with; and they form a great obstacle to the production of good iron from many ores. The silicium, however, is to a considerable extent, extracted by forming a slag (chemically, a silicate of iron), that becomes fluid under the intense heat of the furnace. The phosphorus is that which is most difficult to deal with. This difficulty, however, as we shall subsequently notice, is now nearly overcome.

The result of puddling is found in the different kinds of iron produced, that have various names, depending chiefly on their appearance. Bright iron, gray, white, mottled,. &c., are amongst these ; and of them, the white is that which is considered to contain the least quantity of carbon when in the form of pig ; and all such mentioned above have less fluidity than the kinds mostly used for casting purposes. Much depends, in respect to the quality of pig-iron, not alone on the ores used, but also on the fuel, because the latter necessarily introduces silica, alumina, sulphur, &c., as obtained from coal or coke. Hence it is that charcoal iron, which is that smelted or worked with charcoal, always obtains the highest price in the market ; and its sole use is frequently a condition in making contracts for the construction of all kinds of articles; but especially large masses made of wrought-iron.

We perceive, therefore, that not only is the old refining and puddling process tedious, but it is also remarkably uncertain. Uniformity of result is impossible under the old system ; and this want of uniformity greatly militates, not only against the economical use of iron, and its length of wear, but often against safety in its use. For example, a defective boiler-plate, railway axle, or tyre, &c., may be the cause of death to scores of persons, unwittingly the victims of the old method of puddling.

Here may be introduced an account of a series of very interesting experiments on the microscopic investigation of iron. As a rule iron in the fibrous state, is that most suited for all purposes where safety, durability and tenacity are required. A crystalline state of iron indicates a liability to constant, and sudden fracture, while the fibrous condition is essential to every form of machinery, subject to incessant motion such as shafting, and almost every form of manufactured iron. A cast iron steam-boiler may at any instant be blown to atoms while a wrought-iron boiler may be made that may be guaranteed for safety for many years, and at any time on careful examination, its probable defects can be easily ascertained. The molecular constitution of iron, is therefore of vital importance, and its neglect may lead to terrible results, as for example, the destruction of the Tay Bridge, on the line between Edinburgh and Dundee, which occurred in 1879, when an entire train was precipitated into the river, with the loss of the whole of the passengers, &c.

The experiments to which we now refer in respect to the "Microscopical Investigation of Iron," by Herr A. Martens, Engineer of Berlin, are translated from "Zeitschrift des Vereins Deutcher Ingenieure." The author remarks as follows:—

"The first impulse to these investigations, which are not to be considered as conclusive in any way but merely as introductory, was given to Mr. E. Schott's remarks on the value of the microscopic investigation of iron for practical ironfounding in his valuable and interesting work on 'Die Kunstgiesserei in Eisen.' The object of this article is principally to show the practicability of this method, to induce further investigation, and to indicate the manner in which satisfactory results can be obtained. The results arrived at by the author are shown in the illustrations, and accompanied by a few words of explanation.

"The microscopic investigation of iron can be practised either upon ruptured or ground and polished surfaces. Observations upon ruptured surfaces are best carried out with magnifying glasses of but low power, because, firstly, the reduction in the intensity of light ; and, secondly, the opacity of the object, interfere with the application of microscopes of high power. A twenty-fivefold linear enlargement is the most suitable, and gives the best and clearest results ; for only few ruptures with very even surface can the power be increased to fifty or sixty times linear enlargement. In all cases is

it necessary to change the distance between the object glass of the instrument and the surface constantly, and form a picture from the succession of observations, which requires some skill on the part of the experimenter.

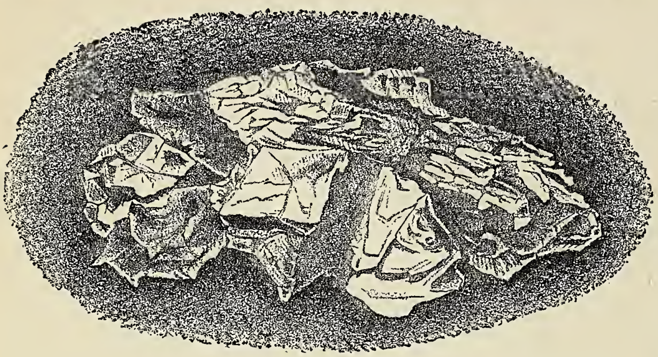


Fig. 95.

"In the investigation of ruptured surfaces of grey pig iron the most prominent parts are the small particles of graphite which entirely hide the metallic iron from view; these show plainly in reflected light the shape indicated in Fig. 95 this figure also shows that the surfaces of the graphite particles are not flat but bent and wrinkled in all directions. The sketch for Fig. 95 was obtained under fifty times enlargement, the surface being etched by hydrochloric acid. Fig. 96 shows part of 95 enlarged 250 times; here it can be plainly seen that the graphite particles consist of small scales, the typical form of which is the equilateral triangle. Almost every one of the graphite scales shows this form when sufficiently enlarged, and the occurrence of graphite can therefore be proved beyond doubt by means of the microscope. These graphite scales are found largest in cavities and on the surface of pig-iron bars. Their size becomes less in the solid iron, from which they may be separated by the action of acids, and they are in the same ratio smaller, as the iron contains less graphite. It is well known that the conditions of cooling have a considerable influence upon the deposition of graphite.

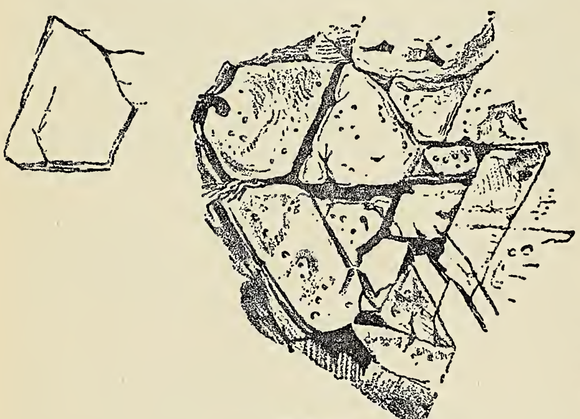


Fig. 96.

"We find further upon the ruptured surface the different iron combinations, and now and then some foreign substances; for instance, silicate. The iron combinations are principally noticed in those qualities that are poor in graphite, the so-called white iron. The ruptured surface of this iron is quite different in appearance to that of grey iron. The little particles are of a more globular shape, of bluish, sometimes silver-grey lustre, which cannot be mistaken from the somewhat greasy appearance of the graphite scales with their typical triangular shape and slate-like arrangement. Some of these scales appear deep black with white outlines in consequence of their position to the light. The structure of such iron, which appears arranged in parallel or radial bundles like the skin of chilled castings, as well as the mottled pig iron, loses materially in distinctness with even moderate enlargement, and is hardly observable with high powers.

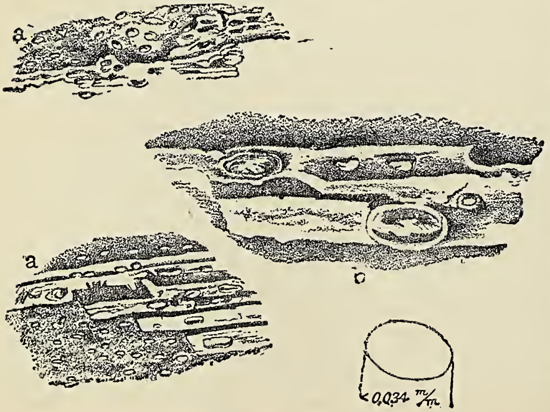


Fig. 97.

"Special characteristic features are revealed by the microscope on spiegel iron. When investigating the fresh rupture, we usually notice some small laminated particles, which, seen with the naked eye in reflected light, show a decided lustre in all cases, whether pure white or coloured by the effects of tempering. When strongly enlarged, about 120 lineal, these small surfaces dissolve into plane surfaces broken up by little globules, and in other places we notice a collection of rectangular columns arranged parallel to each other, as

shown in Fig. 97*a*, enlarged a hundred times, and also covered with the small globular bodies, which are pretty regular in their distribution. Fig. 97*b* shows these in 300-fold enlargement; the size of these globules varies from about 0·01

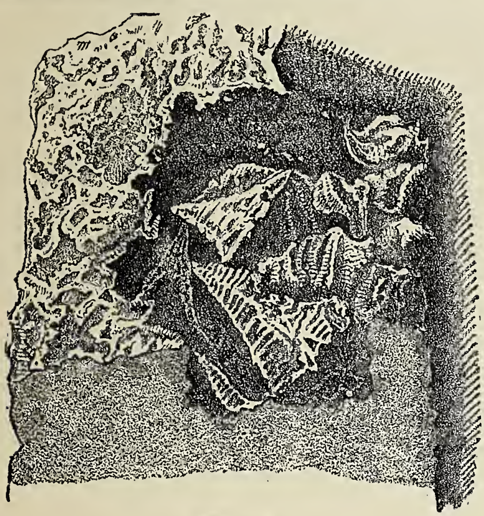


Fig. 98.

to 0·3 millimetre, and about 1,200 to 1,500 of them may be found upon the space of one or more millimetres. These formations are almost invariably most brilliantly coloured, and give a remarkably pretty effect under the microscope.

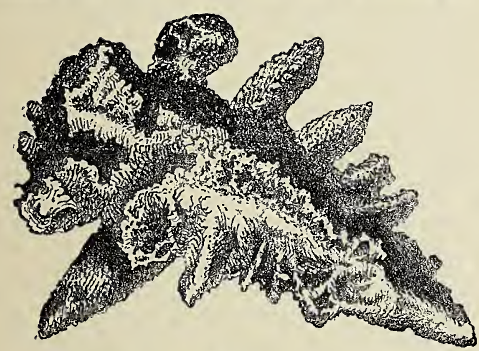


Fig. 99.

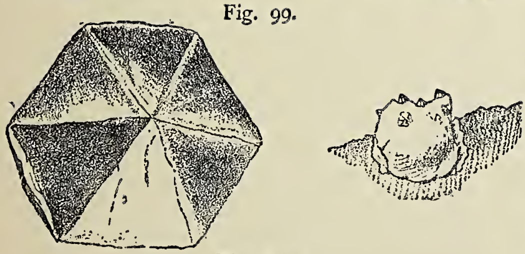


Fig. 100.

Besides this we find in spiegel iron sometimes pure white surfaces, broken only by very fine cracks, crossing each other in two directions, and now and then covered with small crystallised laminæ or needles, which show most perfect polished surfaces under the microscope. Whenever one of these spiegel crystals appears in fracture parallel to the surface, the structure is of a fine-grained pure white colour, if, however, broken vertical to the surface, the fracture shows the particles arranged parallel to each other, and at right angles to the surface.

"We have in the above touched upon the forms of crystalisation of iron, and we may remark here that crystals also occur in grey pig iron, and that the investigation of them is very interesting; to these belong the so-called Tannenbaum crystals (fir-tree crystals) described in the pamphlet, by E. Schott, already mentioned and illustrated above by Fig. 98. This piece was found inside a very heavy casting; the typical crystalline form is that indicated. Some of the smaller branches of these crystals are shown enlarged eighty-fold in Fig. 99. When examining these I have noticed some very interesting points, but it would take one too far to explain them here; it may, however, be mentioned that in consequence of these formations being mostly found in cavities of large castings, they show all the most beautiful colours that occur when tempering iron. In ruptured surfaces of similar castings I have hitherto been unable to discover similar formations, although Mr. Schott mentions their occurrence. This casting was blown with coke; I have, however, in some charcoal iron, noticed, in several cases, similar formations in the homogeneous metal mostly of very elongated form. I am not in a position to say positively if any conclusions can be drawn from the length of the main axis of these crystals upon the quality of iron, because I have not yet been able to carry out a sufficient number for comparison; but taking into account the various occurrences of these crystals which I have investigated, I am inclined to believe that this may be done. One formation that I have only met with once, but which I consider of sufficient interest to mention, is shown in Fig. 100, consisting of a number of small crystals distributed over a sphere; the crystal itself is shown 180 times enlarged, and I have not been able to ascertain the compositions of these little crystals, which only measure about 0.02 mm. in diameter.

"I now come to that class of microscopical investigations which I consider the most useful for practical purposes, the investigations of ground and polished surfaces. It is here, as in the first class of observations, advisable to employ only limited power instruments; enlargements of 200 linear are for almost all purposes sufficient, and with this power I have found it another advantage to be able to place the object fixed upon the object-holder in such angular position that most of the reflected light from the surface is thrown into the field of vision of the microscope. By altering the position of the lens you can get all parts of the object sufficiently sharp and clear in succession. If Canada balsam and covering glasses are used, it is not necessary to bring the object in this angular position, but the balsam somewhat interferes

with the clearness of the vision, and in time changes the colour of the object.

"To prepare the thin slices of iron for the microscope requires both skill and patience, because the surfaces must be very even and of a perfect polish. With some practice, however, it is not so tedious an undertaking as one might imagine. The best way is to fix a piece of the metal filed as thin as possible and not larger than about $\frac{3}{16}$ in. to $\frac{3}{8}$ in. square by means of shellac to a piece of wood and grind the metal with emery and water upon a thick glass plate about 10 in. to 12 in. square. When reduced to the required thickness, fine washed emery is employed for finishing, and a new glass plate must be used for this purpose. The third and last operation is polishing the surface; this is done with oxide of tin or some other polishing material and water upon a third glass plate. The investigations may now take place either upon the polished surface or after the surface has been etched with different chemicals. Upon the polished surface, particularly of grey iron containg much graphite, the microscope shows cracks, scratches, holes, &c., and different though very indistinct shades. The cracks are found in all possible directions, and differ much in closeness and distribution, as may be seen from Figs. 101 and 102, the former 25, the latter 50 times enlarged. In most cases these cracks are noticeable with the naked eye, and are caused by small particles of graphite intersecting the metal. These softer graphite particles are more easily cut away by the grinding and polishing materials, and their presence is therefore indicated in the metal surface by a slight deflection. As is well known, grey pig iron is a mixture of various iron combinations, probably of different density and hardness, which are differently affected by the grinding material, and consequently show different shades on the polished surface; it is further likely that the various combinations may vary slightly in colour. The mottled grey pig iron shows a structure which may best be described as 'knitted,' caused as well by different shades in colour as also the distribution of the graphite cracks. This is particular noticeable in Swedish gun iron. In the latter we can distinctly see, especially under higher power instruments, the difference between the white harder and higher polished iron, and the darker ground which gives a mottled appearance to the surface.

"Considerably different is the appearance of spiegel iron; the polished surface of this shows almost always the lines, in which the graphite particles intersect the metallic surface, unless the section be specially chosen. Most of these peculiarities may be seen in the polished surfaces without any etching being employed, as illustrated by Figs. 101 and 102, but all these qualities show very much clearer, and are much more prominent after the surfaces have been treated with chemicals. The most suitable acids for this purpose are hydrochloric and salicylic acid, but whatever may be used, it is always of great importance to employ the utmost dilution. The clearness and sharpness of the picture mainly depends upon the high polish given to the surface and the slowness in the action of the acids.

"I have found salicylic acid the most suitable in many cases, and have obtained the greatest sharpness in outline with a dilution of one part of salicylic acid, which is obtained by dissolving one part of acid in nine parts of alcohol, and in 10,000 to 15,000 parts of water. The metal slices are exposed to the action of the acid for between a half and three days, and may, if necessary, be cleaned with a brush occasionally.

"The pure metallic iron is hardly affected by the acid, spiegel iron not until after considerable time, and appears, wherever mixed in the section with other softer and darker coloured materils, with sharply defined and mostly with peculiarly broken and ragged outline. If the spiegel iron is predominant and in larger patches, we generally notice it covered with small but regularly distributed holes, which seem to correspond to the small globular particles that are noticed in a rupture of spiegel iron. In some cases these little holes are so close together and run into each other in such a way that they form regular patterns on the surface, such as are shown two hundred times enlarged in Figs. 103 and 104. This is a section of spiegel iron from Rolandshütte, exposed to the action of sulphate of magnesia; the deeper etched parts again show different graduations of shade as well as of colour, partly also due to the action of the acid, and in some cases it is quite possible to distinguish two or three decided shades.

"In the grey pig irons the graphite particles are generally distinctly marked and more or less elevated above the surface of the iron, according to the influence of the etching fluid.

"Different variations in the composition of iron may be still better observed by exposing polished sections of the same piece to different acids, or by exposing the etched surfaces carefully to heat, thus producing the temper colours on the metallic surfaces. These colours are remarkably bright under the microscope and very sharply defined in their different shades.

"A careful observer of all these results cannot but come to the conclusion that in pig iron the various combinations of iron are only mechanically mixed, that during the process of cooling or crystallisation they arrange themselves with most astonishing regularity, and that the microscopical investigation of iron has a very great chance of becoming one of the most useful methods of practical analysis. To attain this end, comparative studies of the kind pointed out in Mr. E. Schott's pamphlet are of the first importance, studies which compare the different qualities of the iron, the conditions of melting, casting, and strength, based on the other hand upon chemical analysis; but in consequence of the great variety and expense of the material to be treated upon it is necessary that the energies of several should be combined to obtain satisfactory result. I have hitherto made but few comparisons of the first kind, but combining the microscopical with the chemical analysis has

been for some time past my principal object, and I believe that practical results may be obtained in this way. As a proof I will quote one more instance. Fig. 105, shows one of the fir-tree iron crystals enlarged fifty times, and the microscope led me to believe that this single crystal could not consist of one homogeneous iron combination, although I could not quite distinguish any graphite particles under the microscope. When dissolving the crystal in sulphuric acid they were clearly shown."

To the practical these investigations will be of great value as showing the mechanical character of various kinds of iron, and their relations to the chemical character or qualities of the metal. We shall have again to refer to this subject when dealing with steel and its various new applications that have been made during recent years.

In describing the nature of this process we may remark that it fortunately occurred to Mr. Bessemer to make the pig iron its own refiner and puddler, and this he does by availing himself of the carbon present in the pig; causing its intense combustion, and consequent rapid oxidation, by a powerful blast of air driven through the molten mass of iron.

For this purpose, a vessel, generally known as the "converter," which is illustrated at p. x, *ante*, Fig. 7, in our introductory chapter, lined with fire-resisting materials, and of any chosen capacity, from that of a hundredweight to several tons, is partly filled with pig-iron in a molten condition. Into this melted mass air is driven by means of a tuyere. "The blast rushes up into the fluid metal from each of the forty-nine holes of the tuyeres, producing a most violent agitation of the whole mass. The silicium, always present in greater or less quantities in pig-iron, is first attacked, and unites readily with the oxygen of the air, producing silicic acid (pure flint); at the same time a small portion of the iron undergoes oxidation; and hence a fluid silicate of the oxide of iron is formed, a little carbon being simultaneously burnt off. The heat, is gradually increased until nearly the whole of the silicium is oxidised, which generally takes place in about twelve minutes from the commencement of the process. The carbon of the pig-iron now begins to unite more freely with the oxygen of the air, producing at first a small flame, which rapidly increases; and, in about three minutes from its first appearance, a most intense combustion is going on; the metal rises higher and higher in the vessel, sometimes occupying more than double its former space; and, in this frothy liquid state, it presents an enormous surface to the action of the air, the oxygen of which unites rapidly with the carbon contained in the crude iron, and produces a most intense combustion; the whole mass being, in fact, a perfect mixture of metal and fire. This carbon is now burnt off so rapidly as to produce a series of harmless explosions, throwing out the liquid slag in great quantities; while the combustion of the gases is so perfect, that a voluminous white flame rushes from the mouth of the vessel, illuminating the whole building, and indicating, to the practised eye, the precise condition of the metal inside. The blowing may then be left off whenever the number of minutes from the commencement, and the appearance of the flame, indicate the required quality of the metal. This is the mode preferred in working the process in Sweden. But at the works at Sheffield (Messrs. Bessemer and Co.'s establishment), it is preferred to continue blowing the metal beyond this stage, until the flame suddenly drops, which it does just on the approach of the metal to the condition of malleable iron."

The preceding account is in Sir H. Bessemer's own words as given at the early stage of his invention but we have concluded the quotation at that point where he goes on to describe the production of steel by a continuance of the process to a further stage, which we shall subsequently describe in connection with the old and new methods of steel production.

Now, the beautifully simple and successful process of directly converting tons of pig into wrought-iron in a few minutes, although involving scientific principles, is readily explained. In the old method of puddling, but little of the surface of the pig is exposed at one time to the action of the hot air that passes over it; hence the oxidation of the carbon progresses very slowly, and requires that the fragments should be constantly stirred up, so as to expose fresh surfaces to atmospheric action and heat. Sir H. Bessemer, on the other hand, by forcing in air into every part of the metal, almost instantly induces those chemical changes that we have described as essential to free the pig from its carbon and silicon. The molten mass, in fact, under such circumstances, is divided much after the same fashion as we notice in the cells of bread; the cells of the molten iron being filled with atmospheric air, occupied in all directions in oxidising the carbon, and converting it into carbonic acid gas. Again, the action is equal throughout the mass, and not partial, as is the case in puddling; hence arises one great advantage or value in Bessemer iron—that of being homogeneous or identical in constitution throughout its mass, whether it be pounds or tons. No danger of flaws exists in the iron; and, indeed, if a good class of pig be chosen to operate on by this process, soft iron, all but chemically pure, may be obtained at little cost, compared to that incurred by the old, tedious, and imperfect method of puddling.

Perhaps the best illustration we could give of the impression that was made on the "iron world" is contained in the following quotation from the address of the President of the Iron and Steel Institute delivered in 1879, or twenty-three years after the Bessemer process was introduced.

"We many of us remember how we were startled when, in 1856, at the Cheltenham meeting of the British Association, Mr. Bessemer published his invention in detail. There was, among the prominent ironmasters of the time, pretty general doubt as to some of the principles he promulgated.

In less than a week from the reading of the paper, trial was made at Dowlais of the system of blowing air through pig iron, with complete success. What in outward form was pig iron, and only differed from it by having been blown through for a few minutes in the most haphazard way, was heated in a mill furnace of the common sort, and rolled into bars, to the great astonishment of all concerned. In fact, an experiment undertaken to show that Mr. Bessemer had fallen into mistake proved the exact contrary.

Fig. 101.

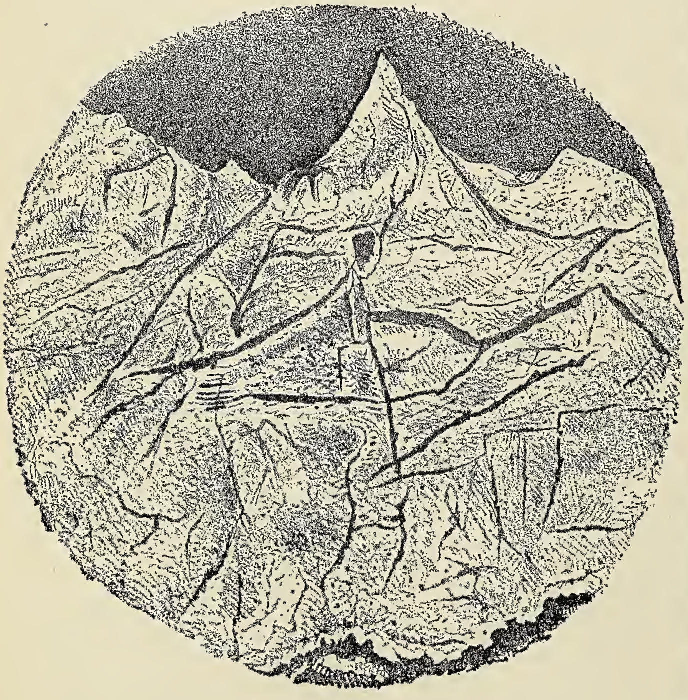


Fig. 102.

"Shortly afterwards the system was set to work on a larger scale, but only very rarely was the success of the first experiment equalled, and generally there was so much irregularity and failure, that, notwithstanding the expenditure of a considerable sum of money, the operations were abandoned as unsuccessful.

"When Mr. Bessemer left Dowlais, where he had been for some time, those who had worked with him, believed that even he feared that the ingenious process he had advocated was not likely to prosper. But if so, his faith soon returned; the clumsy converters first designed gave way to the beautiful tipping vessels; his works at Sheffield were started, and we owe it to his indomitable courage and perseverance that the world did not miss a great advantage."

Such is a general account of the Bessemer plan of converting pig into soft iron; but certain precautions, not yet noticed, must be taken to produce the best results. If the blowing is continued too long, the iron itself becomes rapidly oxidised; and although the silicon and carbon originally in the pig have been got rid of, a difficulty arises, through the production of the new oxide of iron—the metal becoming brittle, or, what is technically termed, red-short. But the addition of manganese has been adopted for the purpose of preventing this result. The manganese is not added in its metallic form; because, from the great trouble of reducing it from its ore, it would be far too expensive; and not only so, it has such an attraction for oxygen, even at ordinary temperatures, that it is impossible to retain it as a curiosity

in the metallic state, except under mineral naphtha; just as is followed, for the same reason, to preserve potassium and sodium. But this difficulty is readily got over. On referring to p. 60, *ante*, a lengthened account will be found of the nature of *spiegeleisen*, a kind of iron prepared from a ferro-manganese ore, and in which the metal is present to an extent equivalent to the requirements of the Bessemer process, in which it is now largely used, especially in the manufacture of iron subsequently to be converted into steel. The manganese in this iron acts as a preventive of red-shortness, arising from the oxidation of the iron in the converter, the oxygen seizing the manganese in preference to the iron. When Sir H. Bessemer first introduced his process, in 1856, he foresaw the difficulty that might arise by carrying this decarburisation too far—that is, by so far removing the carbon as to risk the oxidation of the iron—and he proposed to add to this decarburised metal, whilst still under operation, a portion of fresh pig-iron, to restore as much carbon as was necessary.

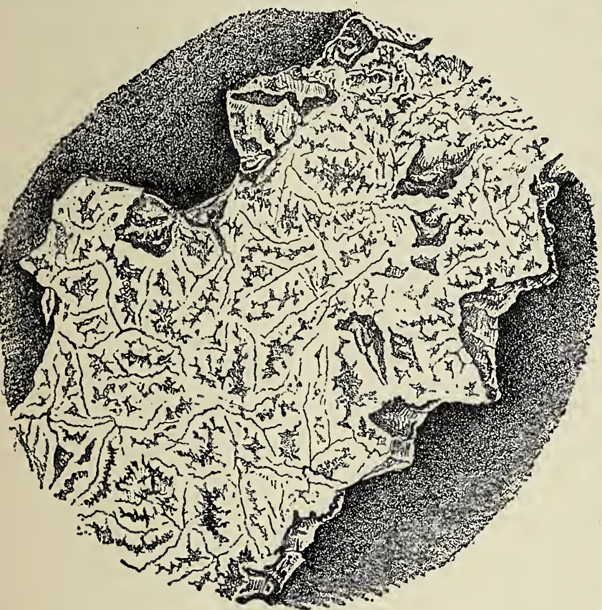


Fig. 103.

But spiegeleisen is a substance of great irregularity in chemical constitution, as we have already explained at p. 60 ; and hence its indiscriminate use would necessarily lead to very uncertain results in respect to the production of soft iron from pig. The difficulty was thus overcome by Sir H. Bessemer : "He melts a known quantity of iron with a relatively large, but indefinite, proportion of manganese. The resulting alloy is not equal in weight to the sum of the constituents before melting; but the loss is not in the iron. Whatever the whole may weigh after fusion, the quantity of the iron is known; and whatever may be the additional weight, it is all manganese, and thus the proportion is known ; and, so that it is known, it does not matter, practically, whether 25 or 50 per cent. of the whole be manganese. And thus the alloy made at one fusion being put aside by itself, there is no difficulty in adding a definite quantity of manganese to a charge in the converter, since it is known exactly what weight of the alloy contains that quantity.

Fig. 104.

But the introduction of manganese into iron has been claimed as first invented by others than Sir H. Bessemer. Mr. Mushet has put foward a statement, to the effect that he had adopted it earlier than Sir H. Bessemer. And we here add another fact, received verbally from Faraday, whilst conversing with him respecting the Bessemer process, in 1856; to the effect that, twenty years or more antecedent to that date, he had experimented on the alloy of manganese and iron, obtaining results precisely similar to those that now make the

Bessemer and other forms of steel of so much value, from containing manganese.

This work cannot in the least be devoted to discussion of any individual rights—a discussion that would be as endless as unprofitable. But in respect to the history of the use and application of manganese, we may properly give the following extract from a paper read by Mr. Mushet, at the meeting of the British Association, at Nottingham, in August, 1866, before the mechanical section, at which Sir H. Bessemer was present, and where he replied fully to the claims thus set forth by Mr. Mushet, in terms we shall afterwards notice.

After some introductory remarks by Mr. Robert Mushet, describing a patent taken out by the late Mr. David Mushet, for the manufacture of refined iron direct from the blast furnace, he proceeded to observe, that the defect in this process was, that the waste of metal was excessive, owing, no doubt, to the surface action of the blast upon the melted iron for a prolonged period. The iron, however, was decarbonised, so as to be in the condition of crude cast-steel: but it was too highly oxygenated to be forged into bars of commercial value. This, he believed, was the first experiment ever made ; but, in the year 1850, he made some further experiments with some highly-blown refined iron from the Park-end iron-works, in the Forest of Dean, and found that when alloyed with manganese, this refined metal could be forged into sound bars of very hard steel—too hard for any practical purpose, but nevertheless solid, and free from seams or flaws, indicating that if the iron could be sufficiently decarbonised while in this melted state, steel of marketable quality might be obtained by simply adding some metallic manganese to the decarbonised metal. In the autumn of 1856 (as already stated) Sir Henry Bessemer read a paper at the meeting of the British Association, held in Cheltenham ; which, whilst it filled the scientific as well as the practical world with wonder, did not in the least surprise him, except in the circumstance of its being possible to maintain a tuyere beneath a heavy column of melted cast-iron. What he had considered impossible had actually been accomplished by Sir H. Bessemer, and the first great advance towards rendering steel as cheap as iron had been made. After describing Sir H. Bessemer's process of operation (see p. 78, *ante*,) Mr. Mushet continued, that when Sir H. Bessemer read his paper, he foresaw all the difficulties he would have to encounter from the oxygenation of the iron, although he knew that the remedy was simple and attainable, provided a suitable metal could be found at such a cost, and in such quantities, as would render its use practicable on a large scale. At last, he (Mr. Mushet) selected the metal manganese ; and his first experiment was with some Bessemer metal, prepared at the Victoria iron-works, from hematite pig-iron. The experiment was made in small crucibles, containing only a few ounces, the Bessemer metal being melted in one crucible, and the spiegeleisen in another. The melted contents of the crucibles were next mixed, and a small ingot was cast. This ingot was forged into a bar of excellent cast-steel, which was doubly welded, and made into a chisel; and it was found, for all practical purposes, to be cast-steel of fair average quality. He then extended the scale of his experiments, and operated with steel melting-pots, each containing from 40 lb. to 50 lb. of Bessemer metal, and melting the spiegeleisen in small crucibles. The most complete success resulted from these experiments ; and Mr. S. H. Blackwell having supplied him (Mr. Mushet) with a small blowing-engine, capable of maintaining a blast of 10 lb. pressure per square inch, he operated upon quantities of melted cast-iron of from 500 lb. to 800 lb., and with similar success; the Bessemer metal being wholly freed from unsoundness, red-shortness, and other defects, which had precluded its being forged or rolled into a marketable product. He secured his invention by letters patent, in 1856 ; but this lapsed in 1859, owing to the non-payment of the stamp duty of £50, through some unaccountable oversight by the trustees to whom he had devised his patent rights. His invention thus became public property ; and he was deprived, by the accident, of all remuneration, which every person practically acquainted with the manufacture of Bessemer metal would admit to be of immense value.

The claim of having thus first applied manganese to iron, as softened after the Bessemer process, is that maintained by Mr. Mushet; but, in replying to this, Sir H. Bessemer pointed out that the use of manganese had long been followed by every steel-maker in the kingdom, and that he (Sir H. Bessemer) had no alternative left but to avail himself of its use. We may conclude these remarks on this subject by stating, that whether Mr. Mushet, his father, or even Faraday, was the first to propose the use of manganese, one thing is quite certain—that Sir H. Bessemer alone has the credit of producing steel in such quantities, and at such a price, as has made it as cheap as the best iron, and reduced its cost to less than a fourth, and in some cases a sixth, of what it previously fetched in the market.

By describing various steps in the Bessemer process, we have been incidentally led into the consideration of the manufacture of steel, to which more especial attention must now be directed.

Steel Manufacture.

The old, but still frequently adopted method of producing steel is that of carburising the best wrought-iron bars. In other words, the pig-iron is deprived, to the utmost possible extent, of all its carbon by refining and puddling; and, subsequently carbon is added to it by different processes. One is that of packing bars of the wrought-iron in cases of fire-bricks, with charcoal, and exposing them to a white heat for some days—a period reaching, in all, to nearly three weeks. By this the carbon of the charcoal gradually and superficially unites with the iron, producing what is called, from its appearance "blister-steel." This addition, or rather

re-addition of carbon restores the fusibility of the iron, previously absent in the wrought-iron state, for reasons already given at page 67, *ante*, where we first described the rationale of the

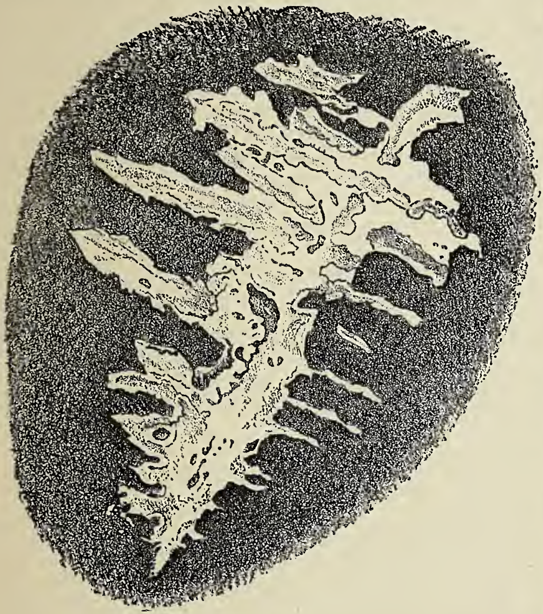


Fig. 105.

puddling process in obtaining wrought-iron. The bars are broken in pieces, and sorted, for their quality is very irregular. The pieces are then put into refractory crucibles, and exposed to a

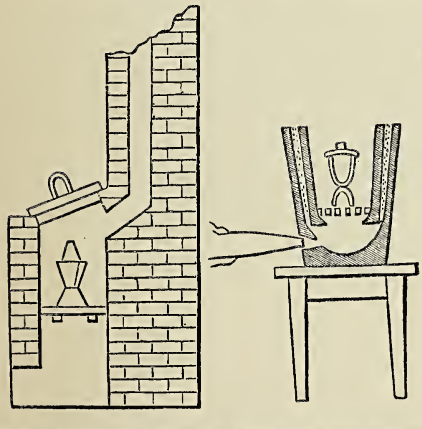


Fig. 106.—Small Wind and Blast Furnaces for Casting Steel, &c.

high heat until complete fusion is effected. (See Fig. 106). The melted steel is then poured out into iron moulds, and produces ingots of cast-steel. Even for small operations, the results of this method are extremely irregular; but if large masses of steel are to be produced, the difficulty is enormously increased, because it is all but impossible to keep up a sufficient supply of the melted metal to produce a really homogeneous mass. The operation is, therefore, not only very costly, but exceedingly uncertain in its results. The carbon is unequally absorbed in the first instance, and possibly nitrogen, that is believed to be a constituent of good steel so produced, is irregularly, if at all distributed. The methods of carburising iron on the small scale are such as involve the use of blood, or prussiate of potass (ferrocyanide of potassium), both of which afford carbon and nitrogen, the latter-named salt giving these two elements in the form of cyanogen, a carbide of nitrogen.

The following gives a more particular account of the old and ordinary methods of producing the following kinds of steel, viz., *blister*, *shear*, and *cast*, than that just given.

The "converting-furnace" is the place where the iron begins first to assume the form of steel. In this furnace is an oblong trough or cell, twenty feet long, three wide, and about three deep. On the bottom of this trough is placed a layer of coarsely-pounded charcoal: then a layer of the iron bars which are to be converted into steel; then another layer of charcoal; then another layer of bars; and so on until there are twenty or thirty of these alternations. The surface is then coated with a kind of clay; all openings are closed, and a fire is kindled in such a position that the flame and heated air may play around the trough without acting immediately on the contents. The effect of this combined heating is, that the carbon becomes absorbed into or combined with the iron, which thereby acquires a molecular character which it did not before possess. One of the bars is so placed in the furnace that a man can draw it out, and test the progress of the operation by the appearance which the bar presents. Steel for different purposes requires different degrees of this absorption of carbon; or, as it is termed, different degrees of "conversion;" and the "converter" therefore manages the furnace according to the kind of steel required to be produced. Coach springs, knife blades, files, razors, and steel for casting—each requires its own particular carbonization or conversion of the iron employed. When this process is ended, the iron has assumed a form which obtains for it the name of *blister-steel*, and in this state it has absorbed about one per cent. of carbon, which seems to act upon it in a way never yet thoroughly understood. The "conversion" is the employment of a distinct class of manufacturers at Sheffield, called "steel-converters;" and the "blister-steel" produced by them is afterwards submitted to other processes, according to the purpose to which it is to be applied.

Scarcely any articles are made from blister-steel, for it is deficient in many of the qualities required in such a material; but after it has been hammered very heavily, it acquires an increased degree of toughness, and is then known as *common-steel*, which is employed for

the cheaper kind of cutlery. A higher quality is that designated *shear-steel*, being such as is employed for shears and a large number of other cutting instruments. The process by which the steel is brought to this state, called "shearing," very much resembles the welding of iron, and depends on the intimate union of many bars of common steel into one. The "tilt-house," where this is conducted, is exposed to a greater amount of violent shaking than almost any other building devoted to manufactures; and it is impossbile to walk through the town of Sheffield without hearing unmistakeable evidence of the vicinity of such a building. The "shearing" and the "tilting" of steel are different processes, but both require the use of enormous hammers, and both are frequently carried on in the same building.

In the "shearing" of steel, the bars of blister-steel are broken up into pieces about a foot long; each of which, after being heated in a furnace, is beaten out by a ponderous hammer to the length of about thirty inches. Next, five or six of these elongated pieces are fastened one upon another into a pile, heated to a white heat, and beaten on all sides until they thoroughly incorporate into one bar. Sometimes this "sheared" bar is broken in two, the two halves placed one on another and heated, and again hammered or welded into one. The degree to which this process is carried gives rise to the distinctions between "double-shear," "single-shear," and "half-shear," as applied to the quality of the steel produced. The steel so produced is much more dense and compact than "blister-steel;" and to make it yet more uniform in substance and texture, it undergoes the further process of "tilting." The bars of sheared steel are heated to a low temperature, placed upon smooth anvils, and beaten in every part for a long time by long powerful hammers. A man sits in a swing, by which he can oscillate to and fro, and bring every part of the bar in succession on the face of the anvil. Great closeness and beauty of structure are given to the steel by this powerful hammering. In Fig. 107 many of these processes are shown: there is a furnace for heating the bars; three of the enormous tilt or shear hammers; the anvils on which they act; the swings in which the "tilters" sit; and three blast-pipes which direct powerful currents of air to blow off loose dust from the faces of the anvils.

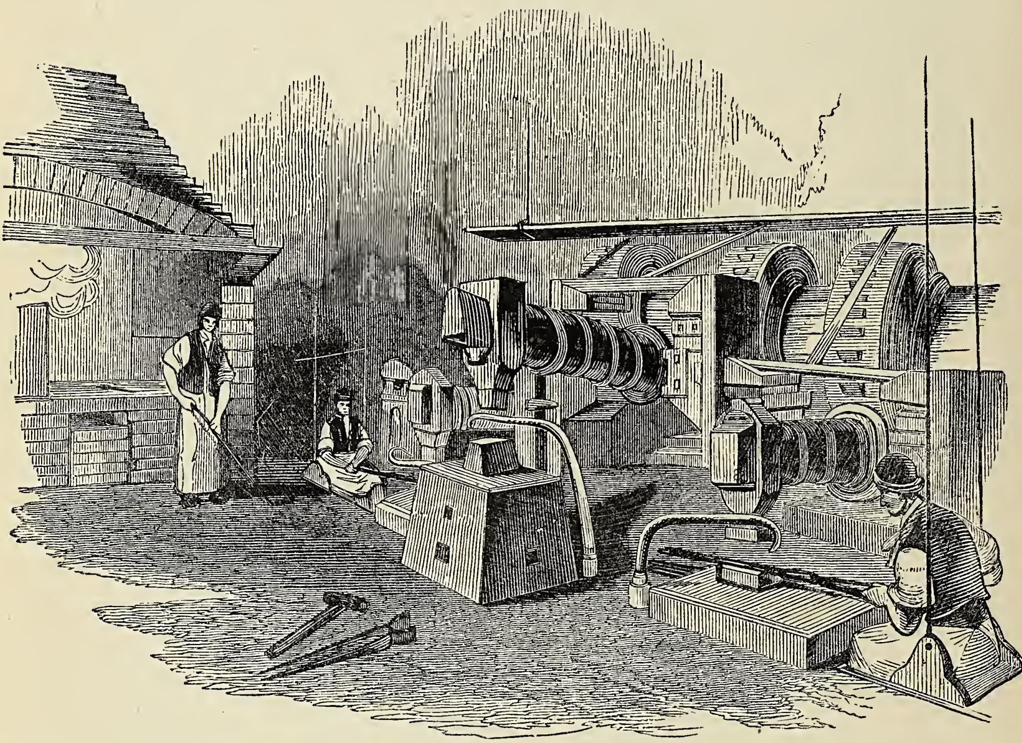


Fig. 107.—Shear and Tilt Hammers: Steel-manufacture.

Perfect as tilted steel may appear to be, it is surpassed for many purposes by *cast-steel*—one of the greatest modern improvements in the steel manufacture. The steel, broken up into small fragments, is put into melting pots or crucibles made so as to bear a very intense heat. The melting pot, at the time of filling it with steel,

is at a white heat, and lies imbedded in a fiercely burning fire in the kind of furnace called a "wind furnace," the mouth of which is a hole in the floor of the cast house. (See Fig. 106, p. 87 *ante.*) A lid is put on the filled vessel; coke is thrown on so as completely to bury it; the cover of the furnace is fitted down tightly, and the heat is then excited to the highest degree—a degree so intense that it is said nothing else known in the manufacturing arts, not even that of a glass furnace, can equal it. Here the melting pot remains until the steel contained in it has become perfectly liquid, and glittering man lifts off the cover; a third removes the adhering slag or cinder from the surface; and the crucible is finally held in such a manner that the contents may be poured out into the mould, which is an oblong brass receptacle standing up endwise. The several stages of this perilous operation are sketched in Fig. 108. How the human eyes can bear the light, and the bodies the heat, to which the steel casters are exposed, is a marvel to all but themselves. While pouring the liquid steel into the ingot mould, there is a profusion of delicate greenish sparks darting around in all directions; and instances have

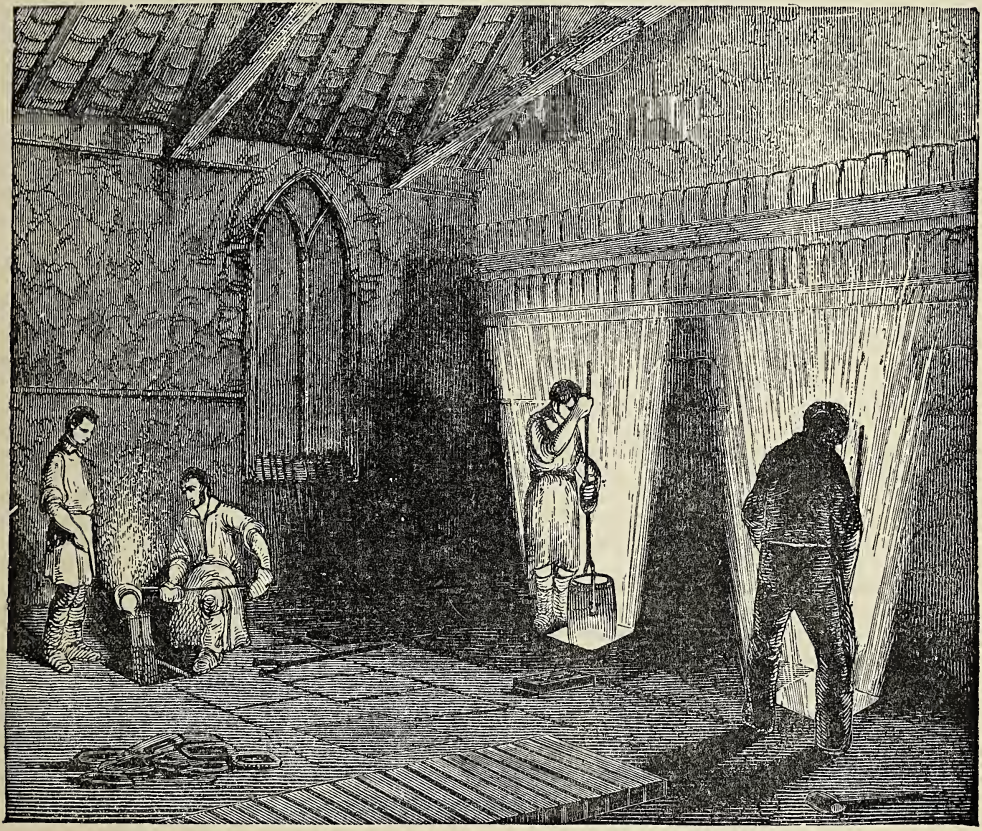


Fig. 108.—Steel-casting: Furnaces, Crucibles, Moulds, Ingots, &c.

with a dazzling fiery whiteness. The office of pouring this liquid steel into moulds is almost fearfully interesting to a looker-on. In the first place, the men employed cover their hands and legs with wetted pieces of sacking and leather, to shield them a little from the heat. The iron cover is removed from one of the furnaces, and amid the bright glare of light which immediately shoots up from the fiercely burning materials beneath, a man is seen to hover over the fire, lower a kind of tongs into it, and draw up the crucible containing the liquid steel; another

been known of the men losing their eyesight by the effect of these sparks.

When the ingots of cast-steel, which weigh from about forty to a hundred pounds each, are cold, they are removed from the cast-house, to be applied to the various purposes for which cast-steel is used. The ingots are heated to a certain temperature and passed between ponderous steel rollers by which they are brought to the state of bar or sheet.

Such is an account of the various processes by which iron, under the old *régime,* and as al-

ready stated, still largely in use now, is converted into steel for the manufacture of cutlery, and many other articles familiar to our readers. It is evidently an expensive, tedious, slow, and uncertain method. We now turn to the Bessemer process by way of pleasing contrast.

The method of producing soft from pig iron as invented by Sir H. Bessemer, has been explained in considerable detail at p. 78 *ante*, *et seq.*, and it is the initiative of his plan of producing steel. He at first adopted the plan of filling the converter (one of which is illustrated by Fig. 7, p. x, in the introductory chapter), with melted soft iron, already produced by his process; and such a proportion of charcoal pig iron as contained the necessary quantity of carbon, and thus steel of any amount of carburisation is produced.

The blast was turned off at the moment of adding the pig-iron, and again let on for a few seconds, to complete the mixture of the charcoal iron with that previously nearly decarburised. As Sir H. Bessemer describes it—

"By this process, from one to twenty-five tons of crude iron may be converted into cast-steel in thirty minutes, without employing any fuel except that required for melting the pig-iron, and for the preliminary heating of the converting vessel, the process being entirely effected without manipulation." The interior of the converting vessel is thoroughly heated by coke, aided by the blast from the blowing-engine, before it is charged with metal; and by merely inverting it, the coke can be thrown out.

It will be noticed in the above brief description of the early Bessemer Steel process the addition of carbon to the soft iron is alone mentioned, but eventually spiegeleisen, already described at page 60 *ante*, was employed, but this question we shall deal with hereafter.

From what has been stated in reference to the Bessemer invention, in respect to the production of wrought-iron and steel, it is impossible not to come to the conclusion that its publication and adoption is not only an event in the iron trade, but also in the manufacturing and commercial history of civilised nations.

Regarding it in its purely scientific aspect, it is simplicity personified. It was our privilege to be among the first to witness, and to bring before public notice, the early steps of Mr. Bessemer's invention, in 1856-'57; and we can well remember the astonishment that it created in scientific circles, and the prejudice that followed it in certain districts in which the iron manufacture is carried on to the greatest extent. But no invention of any merit has ever yet been made that was not characterised by two circumstances—that of simplicity first; and, secondly, primary and determined opposition to its speedy adoption. It is not difficult to account for either of the circumstances to which we have alluded. It is evident, that the more simple the methods we adopt to obtain any end, the less difficulty must arise in their use; for skill and experience are thereby laid aside, and pure routine alone becomes necessary. Nor is it to be wondered at that a spirit of opposition to such an invention should arise. Those accustomed for years to intricate processes, cannot possibly understand how the end they have arrived at can be accomplished by simpler means. Night and day, diligent in business, they have been so accustomed to attending to the minutiæ of processes with which they have been so long acquainted, as to consider it a question of absolute impossibility to hope for success in the absence of all detail of the known and tried methods. And it was no matter of surprise to us when, personally explaining the beautiful simplicity of Bessemer's wrought-iron process to a large iron-master not far resident from the iron metropolis of Scotland, to hear from him that he considered it literally (and we must use the word) "humbug." Patient perseverance, however, from the earliest days of man to those of Bessemer iron, paraffin, and aniline, has conquered; and we may congratulate ourselves, that each of the inventions just named, although at first initiated by foreign chemists or physicists, laid dormant until British intelligence and British capital made them not only of world-wide use, but of universal benefit to mankind throughout civilised and savage regions.

One aspect of this invention, so far as it bears on the commerce of this country, is especially important. It is, that although the Bessemer process is now so well known, still the method of adopting it in England is so much esteemed, that orders for the material produced by it are sent from all parts. We therefore do not only gain the advantage of pecuniary results, but also maintain the character for manufacturing ability, so long enjoyed by this country. Indeed, from this circumstance it would appear, that even had the invention been one of foreign origin, we could have still maintained our character as a producing nation, even in its adoption.

But, despite the perfection to which the Bessemer process has arrived, there are certain accessory conditions to its success that we must here notice. And first, we may state that all kinds of iron ore are not susceptible of adaptation to it. Some found in England, if not in Scotland, are not at all adapted to this process, because they contain a certain amount of phosphorus and sulphur—constituents of an ore almost destructive of any value in some cases, but especially in that wherein the Bessemer process is followed. But, as we shall see in the sequel, this difficulty has been surmounted to a considerable extent.

The value of any invention, in all cases, must to a large extent, depend on the universality of its applications, because circumstances, geological, mechanical, or chemical, may arise, whereby its uses may become practically impossible. But beyond these conditions, there may arise others, that will materially add to the difficulty first to be encountered. In respect to some of our own ores, the presence of phosphorus and sulphur has been highly detrimental, except in special cases (as, for example, the hematite ores used at the Barrow works, mentioned at p. 76, *ante*).

It has been, therefore, a question how far, by chemical means, we can countervail the disadvantage referred to, and use other ores such as that of Cleveland.

It would seem that, according to chemical principles, the introduction of some substance capable of uniting with the phosphorus or sulphur, presents the most feasible means; and, for this purpose, *lead* has been proposed. As our readers will already have gathered, the Bessemer process much depends for its success, not on the fuel employed, as was the essential condition of the older process of refining with puddling, but on the purity of the ore. But such a condition, as already stated, is incompatible with its universal application.

We must own (and it is a great risk to give a decided opinion on so uncertain a subject) that the entire elimination of phosphorus and sulphur from any kind of iron ore possessing those most unfortunate ingredients or constituents, seems a problem that modern chemistry has yet but partially solved with the exception hereafter to be described. No practical chemist can ignore the fact, that, despite all our professed knowledge of what we shall most unscientifically denominate "phosphoric compounds," we are yet, to a very large extent, ignorant of their nature. It is useless to talk of their basic properties, because, under that generic title we simply disguise an ignorance that has been much availed of in certain quarters, to found what was hoped to be well-defined theories. There are certain analogies in science that we may rely on; and there are others that, like the "Will-'o-th'-Wisp," lead us on to error. It is the part of the philosopher to define the limits of each of the extremities we have suggested. But it is equally the part of man to fail in the attempt.

As a matter of historical interest, we quote the following remarks on the state of this question (the elimination of phosphorus from certain iron ores) as it existed in 1867. We avail ourselves first of the experiments and opinions of Mr. Baker, Associate of the Royal School of Mines, published in that year.

"England possesses splendid machinery and plant for making Bessemer steel, but lacks a supply of suitable raw material. By far the greater proportion of pig-iron produced in this country will not make a good rail or crank axle: still less a steel that will burden and temper, or be fit for cutting tools. The reason of this has been well established. The pneumatic process (that is, the blowing in of atmospheric air, that we have already explained as the essential part of Sir H. Bessemer's invention) does not oxidise (or rather remove) phosphorus and sulphur. How they are removed in the puddling furnace (see *ante*, p. 67) is, perhaps, not quite explained. * * * * Dr. Percy inclines to the belief that most of the phosphorus is eliminated by eliquation; that is, that the iron containing phosphorus, being more fusible, does not get balled-up, and so passes into the slag. Giving due weight to this opinion, I venture to observe, that intimate contact with the silicate of iron slag, which affords nascent oxygen, is almost the only explanation besides the one (just) quoted that can be given. Now, herein the Bessemer process differs from the puddling process, when regarded as a refining operation (see *ante*, p. 67.) In the former we do not have anything so like an oxidising a slag, nor (even) so much of it. Often, rounded lumps of nearly pure silica are found mechanically mixed with the fluid slag; showing, that although the silicon (or, as we have previously termed it, 'silicium') has become oxidised (see *ante*, p. 67), there has not been time enough for the proportion of iron to be oxidised, that would form, in combination with it, a fluid slag. It must be remembered that the puddling process only effects the removal of a portion of these impurities.

"Quoting from Mr. Parry's statement in Dr. Percy's work *(on Metallurgy)*, only one-third of the sulphur, and one-fourth of the phosphorus, are eliminated. It is easy to explain this result, if we consider, that from the moment the iron commences to stiffen, the slag becomes less intimately mixed with the charge, and acts on a diminishing surface. This is probably just at the time when, having oxidised the carbon, sulphur and phosphorus would be attacked with more energy.

"Now, although the charge is always fluid in the Bessemer kettle (converter), the slag has evidently less chance of acting as an oxidiser."

Referring to a variety of experiments with lead, intended to remove the phosphorus in certain ores, Mr. Baker observes that Richter appears to have used lead with a view to make white iron (see *ante*, p. 61) available for the Bessemer process, as hitherto only gray irons have been found suitable. "The white iron here meant was, I presume, an iron not only with the carbon combined (not in the graphitic form) but having only a small percentage of that element. It was thought that lead would act as a substitute; and, whilst burning, give time for the elimination of impurities; thus making up for the deficiency in carbon. It was even expected that the cessation of the peculiar flame, due to the combustion of the lead, would be a guide to the operator.

"The experiments with litharge, or lead, in the puddling and melting furnaces, I am afraid have not turned out promising, notwithstanding the reported use of lead at Turrach; but this is a matter about which there should be no doubt. There are a number of chemists attached to iron and steel-works who are well qualified to solve this question. Analysis of samples of a normal charge, before and after treatment, is all that we want.

"Experiments of this kind, if carefully recorded, are useful, even if unsuccessful. I venture to send you notes upon the action of zinc on iron in the melting furnace, and in the Bessemer process. It is difficult to realise in the laboratory, on a small scale, the conditions necessary for such experiments. * * * * To a charge of two tons in the Bessemer converter, thirty pounds of zinc were added, and the blast turned on as usual. The zinc flame

passed off, apparently, in about five minutes. No observation was made with the spectroscope. The metal was tapped, and did not appear to differ from the ordinary castings of the quality employed, which was designed inferior.

"A sample of the charge of iron, as run out of the melting furnace, contained—sulphur, ·0361; phosphorus, ·1720 per cent.

"After treatment with zinc, and blowing, the ingots contained, of sulphur, ·0267 per cent.; and of phosphorus, ·1500 per cent.

"In the melting furnace, 1 per cent. of zinc was melted into a charge of three hundredweight of gray iron, with the following result:—Before treatment, there was 0·160 per cent. of sulphur present, and 0.437 per cent. of phosphorus; after treatment, there was ·0200 per cent. of sulphur, and 0·375 per cent. of phosphorus.

"Further comment is needless. * * * * Zinc will not remove these impurities. It, however, did not make the metal worse; for a two-ton charge, with thirty pounds of zinc, when the metal was of the proper quality, produced ingots which were made into rails of the usual excellence.

"I had also occasion to notice the reducing effect of the mass of iron in the Bessemer operation, when I passed into the blast powdered anhydrous sulphate of iron. I found that, instead of this reagent acting as an oxidiser, sulphur was reduced and carried into the charge. It should be stated that the powder was blown in at an early part of the operation."

Various other methods were tried at the period just referred to (1867) and subsequently, but they all turned out comparative failures until in 1879, Messrs. Thomas and Gilchrist, discovered a new method which seems to have quite solved this serious difficulty. We quote the following description of it from "Engineering" as being one of the most complete we have yet met with:

"The subject which is of most interest to the metallurgical world at the present time is the invention of Messrs. Thomas and Gilchrist for removing the phosphorus from iron in the Bessemer converter, thus enabling the Cleveland and other phosphoretic ores to be used commercially in the manufacture of steel. Many attempts have been made to eliminate the phosphorus from these ores in such a way as to render their use remunerative for steel making, and some of the best known metallurgists in this country and abroad have devoted their minds for years to achieve this object, but without success. It was therefore not without some degree of surprise that the announcement was received of the problem having been solved, and that not by the people to whom eyes had long been turned for tidings in this direction, but by a couple of young men hitherto unknown to fame. The fact that the invention had been taken up by the great firm of Bolckow, Vaughan, and Co., and was being successfully tested on a large scale, of course lent weight to the announcement, and sufficiently accounts for the immediate and intense interest excited in the Cleveland district, and indeed throughout the whole iron and steel trade of this country and abroad.

"The destruction of the iron rail trade, and the advance of steel into other branches of industry had destroyed in a measure the special advantages, and much of the prosperity of the Cleveland district. To compete in the steel trade with the manufacturers of the west was difficult when the hematite ores used had to be imported from Cumberland and Spain, and but few firms were bold enough to undertake the venture involved. It is little to be wondered at then that the reports of the new invention, by which Messrs. Bolckow, Vaughan, and Co. were about to make steel in large quantities from the Cleveland ores, should have sent a gleam of hope over the neighbourhood, and should have brought forth reminiscences of the days when the founders of this same firm first discovered ironstone in the Cleveland hills, and starting ironworks close by on the banks of the Tees, created, in a few years, the important and populous town and neighbourhood of Middlesbrough. The local papers naturally indulged in sentiment, and not a few of their contributors broke out in verse, while ironmakers, though still incredulous, began to count the thousands that might have to be expended in a possibly imminent reconstruction or conversion of their plant.

"We are concerned, however, at present with the invention itself, and its mode of application, rather than with its effect upon the well-being of particular neighbourhoods, and a description of the process will doubtless be of interest, especially as the accounts that have been published in most of our contemporaries have been more or less incorrect in some features.

"It has been said in the press over and over again that the invention consists simply of a new magnesian lime lining for the Bessemer converter, which lining having an affinity for the phosphorus absorbs it from the iron; and the success of the invention has been supposed to depend upon how long this lining would bear the intense heat of the converter without being destroyed, and without becoming charged with phosphorus to such an extent to lose its virtue. This description is, however, by no means correct. The new lining does not, as a matter of fact, absorb the phosphorus, and hence the fear of it failing through becoming charged with the latter is purely imaginary. The only enemy to the new lining is the intense heat, and this it has been found as capable of withstanding as the ordinary ganister lining, or even, it is said better. The invention is in point of fact like all great and useful inventions, extremely simple in its conception, and is based on well-known chemical and metallurgical laws, and the difficulties met with were those incident to carrying it out successfully in practice. The latter have occupied the skill and exercised the patience and energy of the inventors during the last six or seven years, and the circumstances which eventually attended the introduction of their labours to the world, some of which we shall briefly refer to in the sequel, are in many respects peculiar, and will, we venture to predict, constitute hereafter an interesting chapter in metallurgical history.

"We shall perhaps best be able to make the process of Messrs. Thomas and Gilchrist as it is carried out by Messrs. Bolckow, Vaughan, and Co., clear to our readers by describing first what occurs in the ordinary mode of making Bessemer steel from hematite ores or pigs. This may be put as follows:—The molten iron from the blast furnace or cupola is run into the Bessemer converters without any other admixture, and the blast is turned on when by forcing cold atmospheric air at a high pressure through the fluid iron by a number of small holes or tuyeres in the bottom of the converter, the carbon and silicon together with other impurities are driven or burnt out of the iron. (see *ante* p. 79). The carbon becomes oxidised and passes off as an inflammable gas, the variations in the colour of its flame, especially towards the end of the blow, indicating the stage of decarbonisation at which the metal has arrived. Simultaneously with the escape of the carbon, the silicon is oxidised, and combines with a portion of the iron also oxidised to form a slag or scoria which floats on the surface of the molten metal. Whatever phosphorus there is in the iron remains there, and it has hitherto been found impossible in the Bessemer converter to 'blow' it out.

"The slag so formed is of a silicious or acid nature, and offers no means of escape to the phosphorus, because phosphoric acid in its nascent state unless it has a strong base to unite with relapses to its original condition and remains combined with the iron as a phosphide. Silica, it should be added, at high temperatures, is a more powerful acid than phosphoric acid, and in point of fact prevents the latter from combining with the oxide of iron in the slag.

"Under these conditions Bessemer steel has always hitherto been made, and the same remark, so far as the acid nature of the slag is concerned, applies to the manufacture of steel in the Siemens-Martin and all open-hearth furnaces.

"In the early days of the Bessemer converter, this acid slag, combined with the intensely high temperature, rendered it difficult to find a lining which would stand the work satisfactorily, but the ganister lining was soon found to give good results, and has been employed ever since. The ganister lining is itself a silicious or acid material, like the ordinary slag, and consequently so long as it could stand the heat and the movement of the metal it answered its purpose.

"Messrs. Thomas and Gilchrist recognised the fact that so long as there was an acid slag in the Bessemer converter, the removal of the phosphorus there would be an impossibility, and they contemplated the conversion of this acid or silicious slag into a calcareous or magnesian basic slag. Such a slag would afford a base with which the nascent phosphoric acid could combine, and thus enable it to be eliminated from the iron. This it was seen could be done, but then came the difficulty with the lining. A ganister lining being silicious or acid would be eaten away by a basic slag, and the latter would be itself neutralised at the same time; so that to render the contemplated action of the basic slag possible a basic lining also had to be provided. And this proved the hardest nut to crack.

"Lime linings had been tried before for various kinds of furnaces and failed. Mr. Snelus, we believe, proposed a lime lining for cupolas and converters about seven years ago, but it failed mechanically; Dr. Siemens has stated in the *Times* that he also tried a lime lining unsuccessfully. Of course there were two difficulties in the way of these attempts, one being owing to the presence of the acid slag in the converter, and the other owing to the intense heat producing great friability and want of coherence in the lime lining. The very principle, however, which Messrs. Thomas and Gilchrist were pursuing relieved them of the first difficulty, and they were not to be deterred by the latter. After patient investigation and countless experiments they discovered they could make an excellent brick out of magnesian limestone containing from 6 to 8 per cent. of silica, 3 to 4 per cent. of alumina, and 1 to 2 per cent. of oxide of iron, by firing it at a very high temperature, ordinary firebrick kiln temperatures being insufficient.

"This, although apparently a matter of detail rather than of principle, was the turning point of their discovery. Many difficulties still remained with these bricks owing to their enormous shrinkage tending, and not only tending, to crack them. The shrinkage in volume is, we believe, from 40 to 50 per cent., and arises we may suppose in great part from a new chemical formation of aluminates, silicates, and probably ferrates, the bricks becoming exceedingly hard and dense. The difficulty of the cracking has now been overcome, and once fired there is no after expansion or contraction.

"We may now describe the process. As at present conducted at Messrs. Bolckow, Vaughan, and Co.'s works at Middlesbrough, the steel is made from Cleveland ore in various sized converters. These converters are lined with the highly-fired magnesian lime bricks before described. We may mention that at Eston, Dowlais, and elsewhere, brick linings have been adopted and found better than rammed ones. Into the converter, before the molten metal is run in, is placed a certain quantity of lime, carefully weighed, and in proportion of course to the silicon and phosphorus in the iron, of which the influence on the slag has to be neutralised. The metal is then run in and the blowing commences in the usual way. After the blow has proceeded some time a further quantity of lime mixed with oxide of iron is put into the converter, and the blow proceeded with until the operation is finished. Towards the end of the blow samples of the iron and the slag are taken out for examination, but this we understand is only contemplated during what may still be termed the experimental stage, when accurate information as to what goes on within the converter is above all things necessary. When the blow is completed, spiegeleisen is put into the converter and the metal run out into ingots or castings in the usual way.

That this invention marks a vast turn in the

prospects of the iron and steel trades cannot admit of a reasonable doubt. That steel will now be made for practically the cost of iron, and will be sold sufficiently near the price of iron to drive the latter out of the market so far as the great industries, such as shipbuilding and engineering are concerned, looks now more than ever like a thing of the immediate future, and should make even the most sanguine ironmakers look their position seriously in the face. That the change, however great the sacrifices of plant it may entail, will tell in favour of the Cleveland district, is also reasonably clear, although no one can count with certainty on an issue so broad and momentous when inventive faculties of man are awakened in self-defence ; and other changes as vast as the one we have been describing are now being freely discussed, and are not without the bounds of possibility.

"That Mr. Thomas and Mr. Gilchrist have deservedly established for themselves a name and position in the history of our steel manufacture is already acknowledged, but we have not seen as yet any searching criticism of the position which their invention should occupy. This, however, will doubtless soon follow. It will be asked whether the inventors have been treading simply in the footsteps of one or other of the great authorities on metallurgy, and been lucky enough to work out in detail and in a practical shape what had been already sketched out for them in theory. We think they are entitled to far higher praise than this, for they have cleared up much that was obscure by formulating as they have the true relation between a basic lining, a basic calcareous slag, and the removal of the phosphorus at high temperatures, quite apart from their practical success in carrying the theory out. It may, of course, be said that the oxide of iron slag used in the puddling furnace is a basic slag, and that this forms the groundwork of Mr. Isaac Lowthian Bell's system of extracting the phosphorus, but this scarcely covers the whole ground.

"It has long been known that in the puddling furnace the phosphorus has a strong tendency to leave the iron at low temperatures, and that at the higher temperatures the tendency is to return to the iron ; this doubtless arising from the increased activity and strength of the silica at the higher temperatures. Mr. Bell's method of procedure, based on this phenomenon, was to run the metal into a bath of oxide of iron at a low temperature, and by agitating the metal in the oxide of iron, the silicon and phosphorus are both removed, but not the carbon. The purified metal is then run off, and the carbon extracted at a high temperature in a Siemens open-hearth furnace. This system is extremely pretty and interesting, but we cannot help feeling that by emphasising as it were the importance of a low temperature, it has tended to obscure the simple property of a basic slag when it is sufficiently fixed and powerful to extract the phosphorus at high temperatures. As a matter of fact, the extreme temperatures of the Bessemer converter and the Siemens furnace were deemed by many, if not by most authorities, to offer an insuperable difficulty to the removal of the phosphorus in them, and when Mr. Thomas stated in 1878 at the meetings of the Iron and Steel Institute that he could remove 99 per cent. of the phosphorus in the Bessemer converter, an 'audible smile' became manifest. Nothing can show more clearly than this that the principle which underlies Messrs. Thomas and Gilchrist's invention had not been clearly recognised in connexion with these high temperatures.

"It may be interesting to mention here that it is found that for good working the slag should contain not less than 33 per cent. of lime and magnesia, while it generally contains over 40 per cent. and under 20 per cent. of silica. In contrast to this it may be stated that the ordinary Bessemer or Siemens slag contains from 1 to 5 per cent. only of lime and magnesia, and over 40 per cent. of silica.

"That some virtue would be found in a lime lining is a belief that has been cherished by many, and we have referred to its trial by Mr. Snelus and by Dr. Siemens. A few years ago also the great German metallurgist Wedding suggested an oxide of iron lining for the Bessemer converter, with a view to making an oxide of iron slag as in the puddling furnace. This has been tried, and proved a failure. In the first place the lining melted, and in the next such a furious boiling was set up as to throw a great deal of the metal out of the converter, and lastly, the phosphorus was only partially removed, a defect in itself fatal.

"And nearly similar objections exist to the addition of oxide of iron alone to form the slag. In reality the lime additions are chiefly looked to by the inventors to form a powerful base, and the oxide of iron which we have before referred to as mixed with the lime for addition to the converter, although it is capable of making a satisfactory base in the puddling furnace, is added here only in small quantities and chiefly to give more fluidity to the slag.

"Summing up the process of Messrs. Thomas and Gilchrist, it may be said to consist of (1) the formation of a durable and "patchable" lime lining; and (2) the production of a calcareous or magnesian basic cinder or slag containing under 20 per cent. of silica, and certain features in the blowing necessary to reap the full advantage of the above conditions.

"It applies, so far as the slag and lining are concerned, to the Siemens-Martin furnace, as well as to the Bessemer converter, and it is being taken up rapidly abroad. It has, we are informed, been tried under Mr. Thomas' instructions at Thy-le-Château in a Ponsard furnace, which is a combination of the Siemens furnace and Bessemer converter, and very admirable results have been obtained when using phosphoretic pig. For open-hearth furnaces the Pernot furnace is probably the best adapted for this process, as it combines the intense heat of the Siemens regenerators, with a movable bottom capable of being got out and got at without lowering entirely the temperature of the furnace, and it can also be kept in motion during the making of a charge, thereby bringing different

portions of the metal in contact with the flame, and considerably reducing the time necessary for each charge.

"In all cases there is, as will be seen, only the one process to go through to make steel from Cleveland ores, as at present when hematite ores are used; and as to the matter of increased cost there has been up to the present time, we are informed, an excess over the cost of blowing hematite pig of considerably less than 2s. per ton, and this is likely to be much further reduced when large converters are employed.

"In Mr. Lowthian Bell's plans for eliminating the phosphorus there are two distinct and separate operations requiring separate furnaces at widely different temperatures, and this increases the cost so much as to render the plan commercially unsuccessful. Mr. Krupp, of Essen, has recently taken out a patent for removing the phosphorus in a cupola, but we have not the details of the system, although we believe it proceeds on the same principle as Mr. Lowthian Bell.

"We promised in the early part of this article to say a word on the history of this invention and the circumstances of its appearance, but the space at our disposal will not permit of more than a brief reference on the present occasion. Mr. Sidney Thomas and Mr. Gilchrist, who have both studied at the School of Mines in Jermyn-street, have been working together at the perfection of their invention for some six or seven years, as we have stated. Mr. Thomas was a resident in London, while Mr. Gilchrist was chemist to the Blaenavon Steel Works in South Wales. The idea of investigations in the direction they afterwards followed occurred to Mr. Thomas, in whose name the patents have been taken out. After making experiment on a small scale sufficient to satisfy themselves of the correctness of the theory they were pursuing, they obtained the assistance of the Blaenavon Company, which was under the management of Mr. Edward Martin. Here they were eventually able by the assistance of the company to experiment with a 9 cwt. Bessemer converter, and at the Blaenavon works they first made successfully their magnesian limestone bricks and proved their properties.

"Having reached that stage, at which they could lay with safety the record of their investigations before the world, they prepared a paper on the subject for the Iron and Steel Institute to be read at the Paris meetings in 1878. It is a remarkable fact, however, and by no means creditable to those responsible, that the Institute in question, which of all others should at once have detected the value of the paper, looked coldly upon it, and it was not admitted to be read. Its contents, however, became known to some of those most interested in the steel trade of this country and abroad, and among others to Mr. Windsor Richards, the scientific and able manager of Messrs. Bolckow, Vaughan and Co.'s Works at Middlesbrough, who was not long in detecting the merits of the discovery and its enormous importance to steel works situate in the Cleveland district. The Blaenavon Works, the early patrons of the new invention, having met with difficulties, the field was soon left open to Mr. Richards, who having seen some experiments made, lost no time in entering into arrangements for putting the system to trial on a large scale. We trust such enterprise will be well and amply rewarded, and that the firm of Messrs. Bolckow, Vaughan and Co. will reap a rich harvest from the promptitude and accurate foresight of their able manager."

We have thus at great length described this most valuable invention. Its importance may be guessed at when we state that the production of pig iron at Cleveland in 1880 was 2,500,000 tons, none of which could be converted *per se*, into marketable steel, except by large admixture with hematite ores obtained at great cost of carriage. As already remarked in the preceding quotation, the employment of steel has greatly replaced the use of iron. Thus now we have steel vessels, boilers, &c., that were formerly made of wrought iron. But steel has the advantage of great tenacity, and consequently of less weight when compared with iron. By the adoption of the Thomas-Gilchrist process it may be made from Cleveland ores at but little higher cost than the soft iron. Hence not only will that district be benefited, but every kind of steel manufacture be of much less cost as regards the material.

In respect to the tenacity of steel, and its fitness for some of the purposes above-mentioned, we may draw attention to some illustrations that show the result of experiments made some time ago for the purpose of testing some Bessemer steel in the early stages of its production. The specimens were reproduced at a meeting of the Iron and Steel Institute in May, 1879, during a discussion as to the relative merits of iron and steel. Remarks were made by Mr. Barnaby, in connection with a paper read by him on the use of steel in naval construction. The position of Mr. Barnaby as chief naval constructor of our dockyards, naturally gave a large interest to the question, as he expressed great doubts as to the safety of steel in the construction of large vessels, but especially in regard to those intended for warlike purposes.

The strictures of Mr. Barnaby naturally called up Sir H. Bessemer, who gave a very interesting sketch of the history of Bessemer steel and especially of Bessemer "Mild steel," from the time of the great invention down to 1879. He remarked that it was just twenty years ago since he stood in the same place to read a paper before the Institute of Civil Engineers on the same question. He referred to the disastrous results which succeeded the first announcement of his invention at Cheltenham (see *ante* p. 84), and to the two and a half or three years' labour he had to undergo before he could come before the world with a practical mode of carrying out his principle successfully. He had grasped the great fact, though he had not grasped the details. He produced at the meeting of 1879 some most interesting samples which had been shown twenty years previously, and referred to

them as follows:—The quotation is from *Engineering.*

"Iron was the first object he sought to obtain before venturing to make steel by his process. The first sample now shown was a little bar of iron 3 in. square, which was bent cold, and which was considered not a bad sample of cold bending. The second sample to which he would call attention, was a little gun, a small and modest production, but one that had its peculiarities. It was a gun made of malleable iron without weld or joint. That it was made of malleable iron he was desirous to ascertain without question, and, in March, he requested Mr. Riley to see it put in the lathe and a small sample turned off, and then to take the sample and analyse it. The result was as follows:—

Carbon	·0014
Silicon	·004
Sulphur	·053
Phosphorus	·049
Manganese	nil
Copper	minute trace.

Mr. Riley ascertained the quantity of iron by two analyses, and the quantity was in the:—

1st.	Iron	99·893
2nd.	Iron	99·787

Taking the average of these two results, it would be seen that the metal

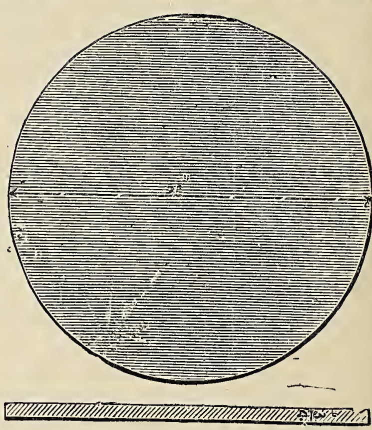


Fig. 112.—Bessemer Steel Plate treated cold.

of the gun contained 99·84 per cent. of pure iron; that was perhaps as near to pure iron as could be got. That gun was made in 1858—21 years ago. It was shown in that hall to the superintendent of the gun factories at Woolwich; and, upon the strength of it, certain cylinders were made of malleable iron and mild steel. He now exhibited a mild steel cylinder of 5 in. bore and $1\frac{3}{4}$ in. in thickness of metal, simply cast and crushed flat under the steam hammer while cold. He also produced a very interesting sample which he hoped would interest those present as a reminiscence of what had been done before. It would be remembered that the vessel first used by him for the converting process was a fixed upright cylinder. This form of converter had been adopted in Sweden, and into it they ran metal direct from the blast furnace; that metal was never made into pig, but was blown and made into ingots in nine minutes. One of those ingots was brought over to England, and was rolled into a circular saw plate of 5 ft. in diameter.

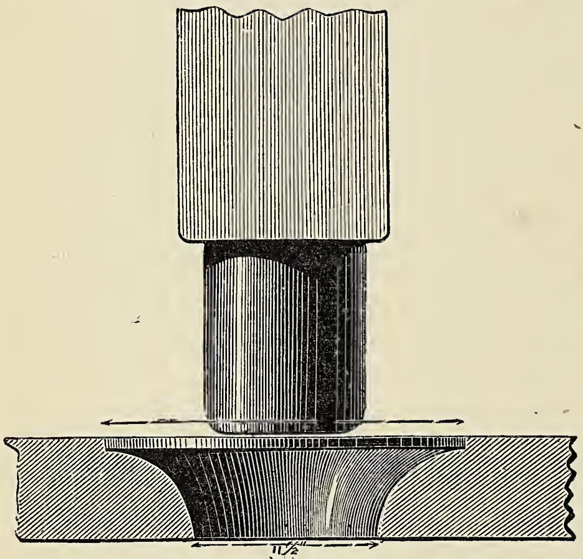
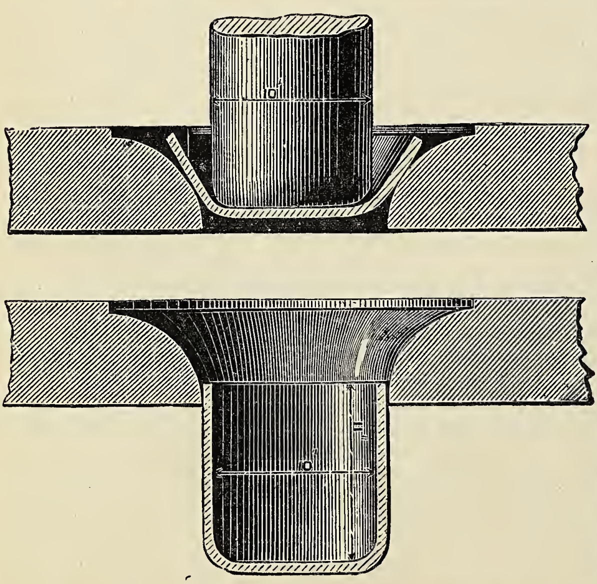


Fig. 109.—Bessemer Steel Plate treated cold.



Figs. 110 and 111.—Bessemer Steel Plate treated cold.

Fig. 113.—Bessemer Steel Rail, twisted cold.

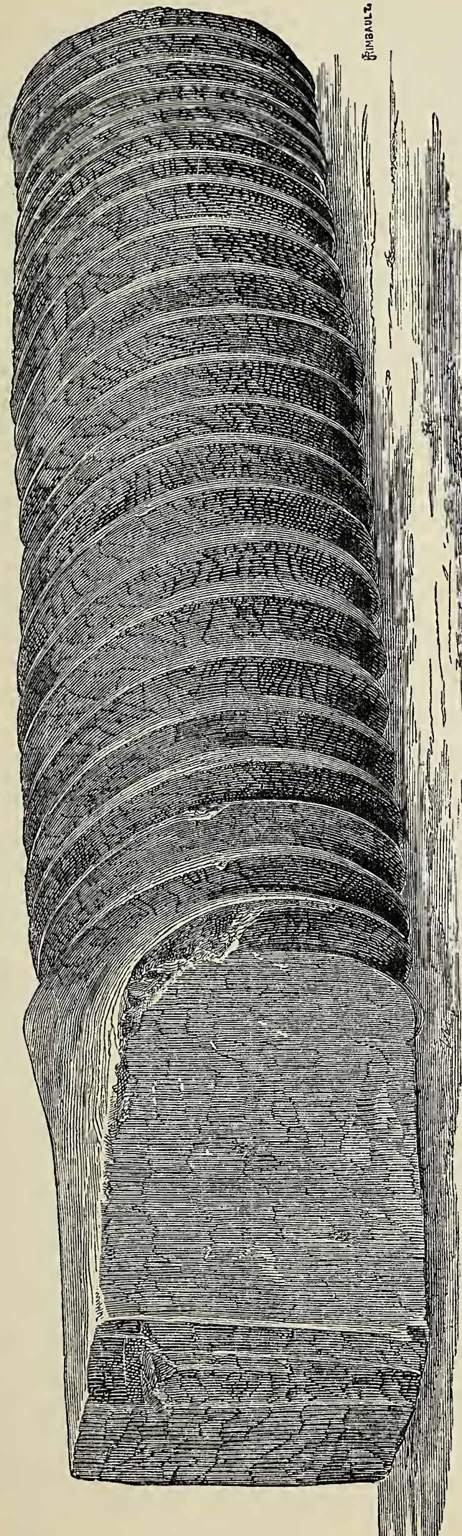


Fig. 114.—4in. Square Bar of Bessemer Steel, twisted hot.

This was the first Bessemer steel ingot ever rolled into a plate in this country; the ingot was unhammered, and was produced without the use of ferro-manganese, spiegeleisen, or recarburation. It was interesting to him, as the result of the first intimation of his process given to the world, through the British Association at Cheltenham. He had also a remarkable sample of the further practical working of this process very soon after the erection of his steel works at Sheffield, 20 years ago. Mr. Parkes, of Birmingham, had invented a system of producing copper tubes by pressing a round disc through a hole by a plunger, thus producing a kind of cup which was subsequently (that is in 1859) extended by drawing in dies to a tube with a closed end. At his (Sir H. Bessemer's) works at Sheffield, Mr. Parkes said he could do the same with steel as with copper, although he was obliged to use the best copper to do it. He (Sir H. Bessemer) then thought differently, and said "It is utterly impossible that so rigid a material as steel could be so treated." But Mr. Parkes was so serious and earnest, that he (Sir H. Bessemer) was induced to go the same evening by train to Birmingham to try it, taking with him three discs of his steel. It happened that at that time his firm were executing an order for locomotive tube plates for the Lancashire and Yorkshire Railway, and one of the discs taken to Birmingham was a piece 27 in. in diameter, and $\frac{3}{4}$ in. thick cut from the end of the plates intended for (Fig. 112) tube-plates. At Mr. Parkes' works this disc was placed over a die with a trumpet-shaped mouth (see Fig. 109), and subjected to the action of a plunger. When it had been forced into a cup shape (see Fig. 110), Mr. Parkes said they must anneal it, and this was

accordingly done, and the steel cup allowed to get perfectly cold. When it was cold it was again put on the die, and a second thrust of the plunger forced it completely through, producing the vessel exhibited (see Fig. 111), without the slightest injury being done to the metal. Thus the circumference of a plate 27 in. in diameter had been reduced to a circle of 11 in. He might be asked why it was not done hot, and he should explain that if they had attempted to do so, the heat would have been abstracted unequally, and a flaw would inevitably have resulted. He did not know how such a thing could be done; he only knew that it was done before his sight; and he took that to be the best evidence of a fact very much disputed, viz., that twenty years ago a mild and tough quality of steel was produced. He had also a very interesting sample that was quite the work of their early days. The president had told them that they had rolled two rails from ingots at Dowlais; he had there the identical rail, or rather a portion of one of the identical rails which were rolled under the superintendence of Mr. Williams twenty-two years ago, and a more perfect rail they were not likely to get, so far as regards the power of rolling. But, in other respects, they had now got a very much better material, for this rail was found to be poor in carbon and rich in phosphorus. He had also a still more interesting specimen, which belonged to the earliest stages of the development of this material, when it was applied to making railway bars, for which it was exceedingly applicable. There was, perhaps, no better practical man in Great Britain that Mr. John Ramsbottom, of the London and North-Western Railway. When he proposed cast steel for rails, to be used on the permanent way, Mr. Ramsbottom looked upon him with amazement, and almost anger, and said, 'Do you wish me tried for manslaughter?' This showed the then state of the knowledge of steel, whose uses were but few. He showed Mr. Ramsbottom, whose mind was thoroughly open to conviction, some samples, and that gentleman said, 'Let me have ten tons to torture and try just as I desire.' Fig. 113 was a good sample of steel of those days. It was a piece of steel rail that had been rolled by Mr. Ramsbottom from a portion of the sample above-mentioned, and had been twisted cold. Another sample exhibited was a 4-inch square bar, which had been twisted hot until the angles of the square formed a kind of four-threaded screw of a pitch, varying from three-quarters of an inch to as little as a quarter of an inch. (See Fig. 114). He also exhibited numerous other specimens of a vase, a jelly mould, &c., all tending to prove not only the tenacity of the Bessemer steel, but also the ease with which it could be fashioned into any form, even when hammered cold."

Such are a few illustrations of the value of the Bessemer steel, from the confectioner's jelly mould to that of vessels of the largest tonnage. Its further applications, with those of steel produced by other processes, will be dealt with subsequently. It may be, perhaps of interest, in an historical point of view, if we quote here a portion of an address delivered at the close of 1880, by one of the most eminent authorities, Mr. Richards, in the iron and steel manufacture. It gives not only the history, but the application of the Thomas-Gilchrist process to the close of that year. The President of the Cleveland Institute of Engineers remarked as follows:—

"Messrs. Thomas and Gilchrist made numerous experiments on a small scale at the Blaenavon Iron Works, where they were assisted by the manager, Mr. Edward P. Martin, and they tried also a couple of casts in a large converter at Dowlais. They prepared a paper, giving very fully the results of their experiments with analyses, which was intended to be read at the autumn meeting of the Iron and Steel Institute in Paris in 1878; but so little importance was attached to it, and so little was it believed in, that the paper was scarcely noticed, and it was left unread till the spring meeting in London in 1879. Mr. Sidney Thomas first drew my particular attention to the subject at Creuzot, and we had a meeting a few days later in Paris to discuss it, when I resolved to take up the matter, provided I received the consent of my directors. The consent was given, and on the 2nd October, 1878, accompanied by Mr. Stead, of Middlesbrough, I went with Mr. Thomas to Blaenavon. Arrived there, Mr. Gilchrist and Mr. Martin showed me three casts in a miniature cupola, and I saw sufficient to convince me that iron could be dephosphorised at a high temperature. I also visited the Dowlais Works, where Mr. Menelaus informed me that the experiments with the large converter had failed owing to the lining being washed out. We very quickly erected a pair of 30 cwt. converters at Middlesbrough, but were unable for a long time to try the process, owing to the difficulties experienced in making basic bricks for lining the converter and making the basic bottom. The difficulties arose principally from the enormous shrinkage of the magnesian limestone when being burnt in a kiln with an up draught, and of the failure of the ordinary bricks of the kiln to withstand the very high temperature necessary for efficient burning. The difficulties were, however, one by one surmounted, and at last we lined up the converters with basic bricks, when, after much labour, many failures, disappointments, and discouragements, we were able to show some of the leading gentlemen of Middlesbrough two successful operations on Friday, April 4th, 1879. The news of this success spread rapidly far and wide, and Middlesbrough was soon besieged by the combined forces of Belgium, France, Prussia, Austria, and America. We then lined up one of the six-ton converters at Eston, and had fair success. The next meeting of the Iron and Steel Institute in London, under the presidency of Mr. Edward Williams, was perhaps the most brilliant and interesting ever held by the Institute. Messrs. Thomas and Gilchrist's paper was read, and the explanations and discussions by other members of the Institute were listened to with marked attention. Directly the meeting

was over, Middlesbrough was again besieged by a large army of Continental metallurgists, and a few hundredweights of samples of basic bricks, molten metal used, and steel produced were taken away for searching analysis at home. Our Continental friends were of an inquisitive turn of mind, and like many other practical men who saw the process in operation only believed in what they saw with their own eyes and felt with their own hands—and were not quite sure then, and some are not quite sure even now. We gave them samples of the metal out of the very nose of the converter. Our method of working at that time was to charge the additions of oxide of iron and lime at the same time into the converter, and pour the molten metal upon them. The quantity of additions varied from 15 to 25 per cent. on the metal charged, according to the amount of silicon in the pig iron used. We soon found that the oxide of iron was unnecessary; besides, it cooled the bath of metal, and we afterwards used lime additions only. After about three minutes under-blow, a sample of metal was taken from the converter, quickly flattened down under a steam hammer, and cooled in water. The fracture gave clear indications of the malleability of the iron. When the bath was sufficiently dephosphorised to give a soft ductile metal, the spiegel was added. Other firms have taken up the manufacture of steel on the basic system, notably the Hoerde Company, in Westphalia, and Messrs. Brown, Bayley, and Dixon, of Sheffield. Very interesting papers on the subject have been read by Messrs. Pink and Massenez, and Messrs. Holland and Cooper. On Monday, the 23rd of August, 1880, I visited the Hoerde Works with a few friends, and saw two successful casts in a small converter. Imitating the good example set me, and having good friends in Messrs. Massenez and Pink, I took a sample of the remelted pig as it was running from the cupola to the converter, and a sample of dephosphorised metal, and of the steel. Mr. Cook's analyses are:—Remelted pig—Combined carbon, 2·75; manganese, ·50; silicon, ·9; sulphur, ·31; phosphorus, 1·51. This analysis agrees with that given by Mr. Massenez in his paper read before the Institute. The metal, after three minutes after-blow, gave phosphorus, ·13; and a further twenty-five seconds gave phosphorus, ·10; carbon, a trace; manganese, ·17: sulphur, ·12. At this stage of the operation a large quantity of slag was poured out of the converter, and then the spiegel was added. The steel contained carbon, ·19; manganese, ·57; sulphur, ·10; phosphorus, ·10; The steel worked well under the steam hammer. The slag was of the following composition:—Iron, 10·20; lime, 46·94; silica, 9·67: phosphoric acid, 9·70. On Thursday, the 20th August, I visited the Rhenish Steel Works, with several members of the Iron and Steel Institute, and the samples brought home were analysed by Mr. Cook, who shows remelted metal to contain:—Combined carbon, 2·90; manganese, 1·10; silicon, ·46; sulphur, ·16; phosphorus, 2·03. The after-blow was very long, being nearly $4\frac{1}{4}$ minutes before the first sample was taken, and a further three-quarters of a minute before the second sample was taken—in all five minutes. The carbon lines appeared on the spectroscope in a few seconds after the converter was turned up. The steel contained:—Carbon, ·28; manganese, ·56; sulphur, ·08; phosphorus, ·08—the metal before the addition of the spiegel having P, ·07. In a second cast, the steel gave:—C, ·27; M, ·40; S, ·07; P, ·10. The slag here is not passed off before the spiegel is added. The sample of slag analysed by Mr. Cook is almost identically the same as that given above from the Hoerde Works. Another cast, made when about 150 members of the Institute were present, contained, I am informed, P, ·13. It was most difficult to get near the workmen who were testing the samples, so great was the crush and the desire to obtain a piece of the metal, and the wonder was that the metal was so well blown and so low in phosphorus, considering the circumstance under which the operation was conducted. At the meeting of this institution in December, 1879, I mentioned that Messrs. Bolckow, Vaughan, and Co., Limited, were about to erect some large converters at the Cleveland Steel Works of a size and from which they expected would enable them to overcome some of the difficulties which they had experienced when working with the old converters on the basic system. This new converter is "concentric," whilst the old converter is "eccentric." During the operation of blowing, the lime and metal are lifted by the force of the blast, and when that force is somewhat expended, the materials fall again on to the bottom in the new form, whilst in the old form some portions would cling to the nose. The "concentric" form has also another advantage: it gives a much larger area of floor to work in, by enabling the metal to be poured into the converter when turned on its side with the nose pointing away from the converter ladle crane, just the contrary of the present practice. On the 18th October, 1880, this converter was set to work on the basic system, and was quite successful, answering the purpose well, and showing no more symptoms of gathering at the outlet than when making ordinary steel. Our plan of operation is exceedingly simple. The converter, as is usual, is first heated up with coke so as to prevent the chilling of the metal. Then a measured quantity of well-burnt lime, about 16 per cent. of the weight of the molten metal, mixed with a small quantity of coal or coke, is charged into the converter, and blown till the lime is well heated. The molten metal is then poured on the lime additions, the blast of 25 lbs. pressure (per square inch) is turned on, and the carbon lines (spectroscopic) disappear in about ten minutes; then, after about two-and-a-half minutes' over-blow the converter is turned down, and a small sample just made, which is quickly beaten into a thin sheet, under a small steam-hammer, cooled in water, broken in two pieces, and the fracture shows to the experienced eye whether the metal is sufficiently ductile.

It it be not so, then the blowing is prolonged, after which the spiegel is added, and is now being poured into the ladle, not into the converter. For the basic process the initial bath should be low in silicon, because silicon fluxes and destroys the lining, and causes a waste of metal; it should be low in sulphur so that the metal may not be red-short. Nearly one-half of the sulphur is eliminated by the basic process. In order to work economically the metal should be taken direct from the blast furnace, so as to avoid—first to avoid the cost of remelting in a cupola; and second, to avoid further contact of the metal with the sulphur and impurities of the coke. It is not an easy matter to accomplish in a blast furnace, the manufacture of a metal, low in silicon, and at the same time low in sulphur. It would, no doubt, very much help to keep sulphur low if manganese were added to the blast furnace, but manganese is a costly metal. At present we have succeeded in making a mottle Cleveland iron with 1 per cent. of silicon and 0·16 of sulphur, and white iron with 0·5 of silicon, and 0·25 of sulphur, which, taken direct from the blast furnace have both made excellent steel. But we have another method of working which relieves us from the necessity of making a particular quality of Cleveland pig iron. We call the second mode of working the *transfer* system, because we transfer the metal from the acid to the basic converter. The transfer system enables us to take any gray iron direct from the blast furnace to the converter without any consideration as to the percentage of sulphur, which is always low in gray iron. This gray metal is poured into a converter with a silicious lining and desiliconised, when after, say twelve or fifteen blowings in the ordinary manner, it is poured out of the converter into the ladle, and poured again from the ladle into a converter lined with dolomite, taking care that the highly silicious slag is prevented from entering into the basic lined converter. Then in the second converter it is only necessary to add sufficient lime for the absorption of the phosphorus of the metal, and the blowing then need not occupy more time than necessary for the elimination of the phosphorus, say about three minutes. This mode, no doubt, will give the basic lining and bottom a much longer life."

There have numerous other patents been taken out of recent years, partly in competition with the Bessemer method or for other purposes. The Siemens process consists in decarbonising a bath of cast iron. The materials must be very pure. No very cheap steel can be made with it but undoubtedly with good materials, steal or ingot iron of the very purest and softest kind can be procured. By the Siemens process wrought iron is dissolved in a bath of cast iron on the open hearth of a reverberating furnace. To make a good article the bath must be pure cast iron, free from sulphur and phosphorus, and the wrought either as scrap or puddle-blooms must be as free as possible from these impurities.

There is one peculiarity of steel that renders it entirely distinct from all other metallic bodies, at least practically, because we are by no means certain that other metals are not susceptible of similar changes. We refer to *tempering*. Indeed, we might, had we space at our disposal, argue that every metal has, more or less, a tendency to change its "temper," from causes connected with the agency of heat. Zinc, for example, can only be rolled at certain temperatures; tin similarly loses its tenacity at some degrees of heat, and may be powdered; and copper has been proved to possess, within certain limits, a power of elasticity somewhat resembling, and arising from the same causes as, that of steel. But still the latter is chiefly characterised by this disposition to temper; and it is therefore practically considered as alone possessing this property.

An old saying has long been current—it is "as hard as a file"—and illustrates the well-known fact that steel may be made so hard as to cut glass; in fact, for this purpose it is constantly in use. There is a certain analogy between steel and glass; for both, on being heated, and suddenly cooled, become hard and brittle. In the case of glass, this may be carried to a surprising extent. For example, if melted glass be dropped out of a ladle into cold water, it will assume a pear-like shape, and may be so collected. If one of these pieces be scratched by a fragment of sand, it instantly flies into dust. Similarly, but to a less extent, steel may be so hardened by first highly heating it, and then plunging it into cold water, that it shall become sufficiently hard to cut any other metal; hence the universal employment of steel for hard tools of all kinds. Very recently glass has been so toughened by exposure to heat, that its natural brittleness has been taken away to a large extent; hence, it shows a still further analogy to steel, as will be presently seen.

But this degree of hardness is perfectly manageable, and the limits of successive qualities of steel, in respect to elasticity and hardness, are perfectly under control. In this consists the art of tempering, and, consequently, the use of steel of various hardnesses for different purposes. Thus, steel suitable for watch-springs and certain tools, would be utterly useless for making pen-knives, razors, lancets, &c. The latter require a degree of hardness which, whilst the article is susceptible alike of polish and sharpness, yet shall sustain a sharp edge for a considerable period. The "spring-tempered steel" would be absolutely useless for such purposes.

The cause of the hardening of steel and iron was the subject of a very valuable paper by Professor Akerman that was read and discussed at Dusseldorf, on the occasion of the meeting of the Iron and Steel Institute in that city in the autumn of 1880. The paper is too long to permit even an abstract in this work. In the discussion that followed, Dr. Siemens stated that he considered that carbon probably exists in iron and steel, not in two forms as is usually conceived, but in three, the carbon in the third form being the hardening carbon. On hardening taking place this hardening carbon may

be considered a changing to the graphite condition. If pressure causes steel to be stronger, then the practice of dipping by causing pressure due to the shrinkage of the outer surface may also be expected to give increased strength. Various other opinions were expressed during the discussion, and the colour tests, to be presently described, were considered by some as by no means always trustworthy.

But generally speaking a pretty sure guide is afforded, in respect to the hardness of steel, and also its elasticity, by the colour it assumes at different temperatures; although, of course, the thermometer is a safer guide. The apparent law governing the hardness of steel is, that any piece raised in temperature from the ordinary condition gets gradually softer. For example, if a very hard file be made red-hot, *and slowly cooled*, it becomes completely softened, the effect of the comparatively great heat being to remove the natural hardness of the instrument. Files are often thus treated to convert them into tools for use at the lathe, being, after shaping, tempered hard again. If a piece of hard steel, however, be raised through a series of successive temperatures—as, say, by immersing it in a bath of mercury or oil—then it will have its hardness diminished in a certain ratio, indicated, as before stated, by the colour it assumes. If quenched at those temperatures by cold water or oil—and by this we mean the ordinary temperatures of such liquids—it acquires certain qualities of hardness and elasticity, denoted by the colour. The following table gives an approximative temperature for each variety of colour, and, consequently, of elasticity and hardness of steel as employed generally in the arts. The temperatures are according to Fahreneit's scale:—

Temperature.	Colour.	Uses.
430°	Pale straw yellow	Razor, lancets, &c.
453	Darker yellow..........	
470	A full yellow	Pen-knives, &c.
490 to 500	Yellow to brown........	
510	Deep yellow or brown, with purple spots ..	Scissors.
530	Light purple	Knives, and many tools.
550	Blue to dark purple	
560 to 600	Dark blue....................	Springs, and several tools.

The above table must, however, in all cases, be considered as approximative rather than absolute in the figures stated; for as the quality of steel varies, so will the temperature at which the colour and qualities above denoted are shown.

The variety of articles, the manufacture of which depends on accurate tempering, is very great, extending from the needle of domestic use (the smallest of steel productions, except the pen), to the chisel of the carpenter, or the cutting-machine of the metallurgist. The watch-spring, chisel and plane of the carpenter, the adze, hatchet, scissors, all kinds of knives, razors, lancets, and other cutting instruments; swords, punches, wire, &c., &c., all depend for their value on an accurately adjusted temper; hence scientific knowledge is an important adjunct to any skill, resulting only from long practical experience. These will be dealt with fully in a subsequent chapter, which will be devoted to the description of numerous articles made from iron and steel.

Many alloys of steel with other metals have been proposed, to substitute the steel itself; and amongst the earliest of such propositions, we may notice those of Faraday, who, in conjunction with Mr. Stodart, published a memoir on the subject, that appeared in Part II. of the *Philosophical Transactions of the Royal Society*, in 1822. At that time, the results obtained were highly important as novelties; but since the discovery of the economical Bessemer method, they have possessed little or no value. Platinum, rhodium, gold, nickel, and silver were alloyed with iron, and interesting philosophical, but unattended with practical, results were obtained. The following, in part extracted from the original paper just named, and partly from Mr. Barlow's account, as abridged from that in the 18th number of the *Journal of Science*, of experiments carried on in the laboratory of the Royal Institution, may prove interesting to some of our readers, and prevent others from incurring an unnecessary outlay of time, labour, and money.

"Alloys of steel with platinum, rhodium, gold, and nickel, may be obtained when the heat is sufficiently high. This is so remarkable with platinum, that it will fuse when in contact [union we presume] with steel, at the heat at which the steel itself is unaffected.

"There are some very curious circumstances attending the alloy of silver. If steel and silver be kept in fusion for a length of time, an alloy is obtained, which appears to be perfect while the metals are in the fluid state; but on solidifying and cooling, globules of pure silver are expressed from the mass, and appear on the surface of the button. If an alloy of this kind be forged into a bar, and then dissected by the action of dilute sulphuric acid, the silver appears, not in combination with the steel, but in threads throughout the mass; so that the whole has the appearance of a bundle of fibres of silver and steel, as if they had been united by welding. The appearance of these silver fibres is very beautiful; they are sometimes one-eighth of an inch in length, and suggest the idea of giving mechanical toughness to steel where a very perfect edge may not be required. The most interesting result is the following:—When one of silver and five hundred of steel were properly fused together, a very perfect button was produced—no silver appeared on its surface; when forged, and dissected by an acid, no fibres were seen, although examined by a high magnifying power. The specimen forged remarkably well, although very hard; it had, in every respect, the most favourable appearance. By a delicate test, every part of the bar gave silver. The alloy was decidedly superior to the very best steel (of that day); and this ex-

cellence was, unquestionably, owing to combination of the steel with a minute portion of silver. It had been repeatedly made, and always with success. Various cutting-tools were made from it of the best quality. * * * *

"Equal parts, by weight, of platinum and steel form a beautiful alloy, which takes a fine polish, and does not tarnish : the colour is the finest imaginable for a mirror. The specific gravity of this compound is 9·862 (a remarkably low value, considering that steel and platinum nearly stand in the value of 8 to 21, in respect to their individual specific gravities). The proportions of platinum that appear to improve steel for edge instruments, are from 1 to 3 per cent. While an alloy of 10 of platinum with 80 of steel, after lying many months exposed, had not a speck on its surface, an alloy of 10 of nickel with 80 of platinum, was, under the same circumstances, covered with rust.

"The alloys of steel and rhodium would prove highly valuable, were it not for the comparative scarcity of the latter metal."

In the memoir already alluded to, as published in the *Philosophical Transactions of the Royal Society*, for 1822, Messrs. Faraday and Stodart observe—"When pure iron is substituted for steel, the alloys so formed are much less subject to oxidation. Three per cent. of iridium and osmium fused with pure iron, gave a button which, when forged and polished, was exposed, with many other pieces of iron, steel, and alloys, to a moist atmosphere: it was last of all in showing any signs of rust. The colour of this compound was distinctly blue ; it had the property of becoming hardened when heated to redness, and quenched in a cold fluid (see our remarks on tempering at page 101). On observing this steel-like character, the presence of carbon was suspected ; none, however, was found, although it was carefully looked for. It is not improbable that there may be other bodies besides charcoal (carbon) capable of giving to iron the properties of steel : and the authors, though they cannot agree with M. Boussingault when he would replace carbon in steel by silica or its base (silicium, already referred to as driven off first as slag by the Bessemer process as far as possible: see p. 78 *ante*) think his experiment very interesting on this point, which is worthy of further examination, notwithstanding the above results."

Many subsequent attempts were made to "improve" steel by various alloys ; but, in all cases, the results were practically of no value; and, as the editor of the *Journal of Science* (in which most of the previously related experiments were first published) remarks—"A bar of the best ordinary steel, selected with precaution, and carefully forged, wrought, and tempered under the immediate inspection of the master, would afford cutting instruments as perfect and excellent as those composed of the alloys"—an opinion since verified by the results obtained by our new processes, in which the purity of the steel is ensured as far as possible.

Two species of foreign steel have long been known for their excellence : we refer to Indian steel, or *wootz*, and the Damascus kind, so noted as a material for the manufacture of sword-blades. Formerly both these kinds were esteemed as of the greatest value; and their mode of preparation was unknown to Europeans. Faraday early engaged in an analysis of wootz, but failed to ascertain the cause of its excellence. It will be unnecessary for us here to enter into any details of what is known respecting these; for, like the Toledo blades, their former importance has disappeared, but they may be noticed hereafter; and if modern productions may be somewhat inferior in some respects, still they arrive as near at perfection as the requirements of the case demand.

Singularly the steel manufacture has assumed a considerable importance in China, especially along the upper Yangtze, from which district the metal is shipped to Tien-Tsin. The price obtained for the steel in China is higher than is secured by that imported from Sweden. Chinese metallurgists recognise three different qualities of steel. The first of these is produced by mixing crude iron with wrought iron, and submitting the mass to the action of fire ; the second, by the repeated heating of pure iron; while the third consists of the native steel, which is produced in the south-western districts. The different names by which these various kinds of steel are known, are the following:—The "twan kang," or ball steel, on account of its globular form; the "wan kang," or tempered steel; and the "wee tei," or false steel. The Chinese seem to have been acquainted with the manufacture and use of steel from the earliest times; and at the epoch of the Han dynasty, ironmasters were appointed in the different districts of the ancient Leangchow, whose duty it was to superintend the iron manufacture. We may here notice that when the Cleopatra Needle, presented to the United States by the Viceroy of Egypt, was lowered from its base, steel tools of excellent quality were discovered.

The specific gravity of steel has often been considered as a test of its value; and, to a certain extent, it is so. All well-hammered or worked metals are of greater specific gravity than such as are cast. Good blistered steel thus has, before hammering, a specific gravity of 7·30; increased by hammering to 7·80, and upwards; whilst the best English cast-steel may, after hammering and tilting, attain a specific gravity of 7·80 to 7·90. Still, there are so many other circumstances that effect the quality of steel, as to make the specific gravity test alone fallacious.

Case-hardening is a term applied to a process by which iron is only superficially converted into steel, and by which, whilst the inner portion of the article retains the toughness of iron, the external part has all the hardness of steel, and is susceptible of being tempered. Case-hardening is usually, therefore, effected on small articles—such as tools, &c.; and the effect is produced by heating the iron in contact with animal matter—such as blood, &c., or the yellow prussiate of potass, which also affords both nitrogen and carbon from the cyanogen it contains,

and already referred to as thus used at a previous page. This process is also called cementation, from an idea that the effect resulting from the usual mode of treatment partakes of that character. In reality, cementation, for this purpose, in nowise differs, except in the weight of article operated on, from the process employed to first produce the blister steel, described at p. 87, *ante*. In the latter case, however, the whole of the mass of iron is converted into steel; whilst, in case-hardening, the external surface is alone affected.

Of recent years a process has been employed to render steel homogeneous or of equal character throughout. The cast metal is subjected to enormous hydraulic pressure by which vacuities, air-bubbles and some impurities are driven out. In the case of large steel guns, heavy plates, &c., the method must be of considerable value, but we believe that its application has not been very extensive.

There is one property of iron and steel to which we must briefly draw attention, but which will afterwards be dealt with *in extenso*. It is that of their being susceptible of magnetism; and, indeed, practically, they are the sole media through which the properties and laws of magnetism can be examined, although nickel and cobalt are, in a minor degree, magnetic.

The natural loadstone is a kind of double oxide of iron, being composed of the protoxide and sesquioxide mixed together. It is found in Norway, Sweden, the Ural and Hartz mountains, Saxony, Bohemia, Corsica, Elba, Spain, India, United States, Mexico, Brazil, in Cornwall, and many other places. As previously noticed, it is a valuable and pure source of the metal; and to this may be added, that it is the most magnetic of any iron ores.

If a piece of soft iron be attached to it, the metal, *temporarily*, acquires magnetic properties, especially evidenced by a newly-acquired power of attracting other pieces of iron. But if the iron be pure, it loses this property on being removed from contact with the loadstone, as this magnetic oxide is frequently termed.

If steel, however, be similarly treated, other phenomena of great interest are then developed. Instead of this metal becoming but temporarily magnetised, it will retain magnetic properties for some time, independent of any subsequent contact with the loadstone; and if this be repeatedly rubbed on the steel, the latter will acquire an equal and permanent power to that possessed by the magnetic oxide.

These facts are of the highest value in both scientific and practical points of view; for the whole phenomena of magnetism, electro-magnetism, dia-magnetism, the application of electricity to telegraphic purposes, &c., &c., are the philosophical consequences; whilst navigation depends for its safe pursuit on the polar power steel thus acquires; hence the mariner's compass, without which the trade of import and export of our day would be simply impossible.

In the first place, we may notice that the power of retaining magnetism in iron depends on the hardness of the metal; hence absolutely pure iron cannot exhibit, of itself, magnetic properties, unless in contact with a magnetised body. But as the metal is hardened, it attains this retentive property until the hardness of steel is arrived at; and thus, to a certain extent, the magnetic properties of a piece of iron may be considered as a test of the carbon present.

But ordinary wrought iron never is so free from carbon as to be absolutedly insensible to magnetic influence, or rather, insusceptible of personal and retained magnetism; and some very curious, and, we add, serious practical results arise from this fact. If, for example, an iron ship be built on the stocks, in such a direction as to be in, or parallel to, the magnetic meridian—that is, the line which indicates on the earth its magnetic polarity—the vessel will not only attain magnetic properties, but retain them for some time. The consequence of this is, that if certain countervailing means be not adopted, the ship's compasses will not only become useless, but positively dangerous. A remarkable instance of this induced magnetism was seen in H. M. S. *Northumberland*, that was launched in 1866, and in which the polar condition was so great as to render the compasses useless until the polarity of the ship was countervailed. Attempts were made to remove this polarity, the principles of which will be more fully explained afterwards.

Now the cause of this magnetism is not simply due to the mere erection of the vessel in this direction (nearly north and south in respect to the bows and stem), but also to the mechanical operation of hammering, that constantly is going on in every part of the vessel whilst it is being constructed. Indeed, an ordinary common poker may be similarly rendered magnetic if it be suspended by a string, so as to point nearly north and south; or more properly, to the magnetic north, the variation of which is about 19° west of north, at the present time, in this country; and, if repeatedly hammered, it will thus have communicated to it the power of attracting other pieces of iron; and, to a limited extent, it will become polar: that is, it will point towards the magnetic poles just as the magnetic needle in the mariner's compass does. All masses of wrought-iron, as now made, and containing even a minute portion of carbon, that gives a certain degree of hardness, are similarly affected if in motion; hence railway axles, the shafting of factories, and other longitudinal masses, gradually become magnetic, retaining this magnetism in proportion to their hardness.

Another interesting, but often serious, result arises attended with a presence of magnetism. After a lengthened revolution of railway axles, shafting, &c., a decided change takes place in the molecular constitution of the metal. No matter how soft or fibrous it may have originally been, it at last becomes crystalline in texture, and the rod or shaft breaks. This fact is carefully considered in railway management; and no axle is allowed to run beyond a certain mileage without being re-forged, by which the crystalline character is removed, and the fibrous restored. In all instances that we have tested in iron so

changed, it evidenced decided magnetic polarity (see remarks on the Microscopic Investigation of Iron, with illustrations at p. 79, *ante.*)

Confining our attention, for the present, to this peculiarity of iron (but, as we shall see, it is met with in other metals), many interesting points of inquiry arise, that modern science has yet failed to satisfy. It may naturally be asked, whether magnetism is a cause or the effect of this crystalline conversion? And, at present, the question has not been satisfactorily decided. The following results at which we arrived by experiment in 1849-'50, will be of interest to many practical readers; and, it may be added, were at that time in part verified by the experience of Faraday, who had noticed the effect to be described, but had not at that time inquired into its correlative influence on metals generally.

If a wire of, say, 10 gauge, made of pure copper, be used, for any length of time, as the conductor of a powerful voltaic battery—as, for example, one of fifty cells of Grove's battery, with platinum plates 4 × 2 inches—no matter how soft it may have been when first so employed, it will speedily become hard, and break with the slightest bending. Many persons will have noticed, that if the terminals of a Rhumkorf coil be bent, if made of almost any metal, they will speedily become very brittle. Indeed, if the terminals of the secondary or intense coil of the ordinary coil machine be often bent, they will snap off like a piece of wood.

The earliest experiments we tried in this matter were undertaken in 1840—'42. Fine *iron*, in place of copper wire (as usually employed), of about 28 gauge, was adopted in constructing an arrangement formed of a horseshoe piece of iron, coated with a primary copper coil, and coated with the secondary above mentioned. At that time we obtained, on a small scale, similar results that have since been so magnificently effected by Rhumkorf's and other electro-magnetic arrangements. But with the fine iron wire there was a constant source of annoyance, through its breaking in various parts of the convolutions of the coil—apparently spontaneously, for no possible force, of a mechanical or external nature, could have been the cause.

On examining the section of the wire so broken, it appeared invariably crystalline, and to have lost most of its tenacity; whilst a precisely similar portion, off the same piece indeed, but that had not been used in the coil, was tenacious, and of good quality.

We have met with two of Rhumkorf's coil, of late years, that gave the same annoyance as that mentioned above, and the cause of which was the same—namely, the breaking of the copper wire, which, like the iron, presented a similar crystalline appearance.

In each of these instances (and, from personal experience, we could adduce many others), it is evident that two forces must have been in operation—namely, magnetism and electricity; and as the wires that had not been subjected to their influence retained their tenacity, whilst those that had been subjected to them lost their tenacity, it is strictly philosophical to suppose that magnetism has a direct action on the molecular constitution of metals, but especially iron.

Reducing the preceding facts to practical purposes, and reverting to what we have stated in respect to iron ship-building, revolving shafting, axles, &c., we may trace similar conditions in nature to those we have instanced as resulting from laboratory experiments. This will appear from the following considerations.

And first in order, we must notice, that the polarity of the magnetic needle, and the dip of the dipping needle, are directly traced to an affection, influence, or force, resident, so far as we now know, in the earth. The magnetic needle is a piece of steel magnetised, and so fixed that it shall only move horizontally; whilst the dipping needle is a piece of steel magnetised, but so suspended that it can only move vertically. It is well known that the horizontal needle invariably points north of the equator, to a part of the earth's surface situated in latitude of 70° 5′ north, and longitude 96° 45′ west of Greenwich. As already stated, in this country the horizontal needle does not point to the true north, but 19° west of it. But, in this country, the dipping needle has a definite position or place in space. If a piece of steel be accurately balanced, so that it shall be in exact equilibrium, and suspended so that it can move vertically; and, if again, after being so accurately balanced it be magnetised, it will, after the operation, *not* balance accurately; on the contrary, it will fall at one end towards the earth, and take an angle of about 67° in the latitude of London. If, however, the same needle be taken to a spot, the latitude and longitude of which have been named above, then it will take a vertical position, one end pointing directly to the earth, and the other to the zenith.

These facts show, therefore, that the earth has enormous magnetic powers; and that, at the place just named, those powers culminate in intensity. In fact, that point or place is the magnetic pole of the earth, as one end of the needle of the mariner's compass is one of its poles. We may, therefore, regard our earth as an immense magnet, acting, attractively and polarly, on all small magnets on its surface; attracting or repelling the poles, according as similar or opposed poles be presented to it.

Going one step further in the science of the question, we may add, that the apparent north pole of the earth's magnetism is a south pole, if we consider the end of our magnetic needle pointing to it as north; the law of magnetism being, that similarly magnetised poles repel each other, whilst dissimilar attract. In other words, a north pole attracts a south, and *vice versâ*; whilst a north pole repels a north, and *vice versâ*—facts easily verified by magnetising two common needles, floating them on water, and successively presenting the identical or opposed poles of each.

Admitting all the facts that have been stated,

we can at once see how it is that an iron ship, shafting, railway axles, &c., become magnetically polar. The earth induces, in each of them, a magnetic force, and consequently converts them into magnets, varying in power according to their hardness; and their retentive power being due to a similar quality of the metal. It is hence certain, that if such a ship as the *Northumberland* (before referred to at p. 103, *ante*) was hung up in the air, so that it could freely turn, it would become as complete a "magnetic needle" as was ever constructed for a mariner's compass. Hence, also, as the earth acts on the ship, the ship acts on its compasses; and the derangement of these is thus explained.

It has been remarked, that the harder the metal (steel), the better it retains its magnetism; and this quality is coincident with the effect of tempering, already explained at p. 101, *ante*. So invariably does this rule hold good, that the quality of many steel articles may be judged of, in respect to hardness and temper, thus:—Rub them with a horse-shoe magnet in the usual manner for communicating magnetism; that is, rub towards one end from the centre with one pole, and with the reverse pole towards the other extremity. Magnetism will be thus communicated; and its amount may be ascertained by noticing how much weight of soft iron one of the poles will sustain. In a few hours, or days, according to the hardness of the steel, this quality will become lessened, the softer articles losing most and quickest; whilst those that are hard may retain their magnetism for years.

It will be thus perceived that the general effect of magnetism on iron is of a temporary character, if it be pure; of a more lasting nature if hard; and, in steel, the effect becomes permanent, or, at least, may be extended over a long period of time. We also notice, that magnetic and electric forces may, and actually do, affect the molecular constitution of iron and steel; which, under certain circumstances, becomes of serious importance in certain branches of manufacture carried on with either or both of those metals.

The test of the value of iron and steel depends on a variety of circumstances, but especially in reference to extension, set, and rupture under tensile or pulling strength. We are indebted for the following tabular results to Mr. Longsden. They were derived from experiments on a piece of broken cast-steel shaft, manufactured with the greatest care in Germany, for the Peninsular and Oriental Company's steamship *Jeddo*. The shaft was sliced up into two specimens, which were subjected to pulling, thrusting, bending, and twisting stresses. A more severe test of the quality and uniformity of the steel could not have been devised; and the admirable manner in which the several stresses were sustained could not have been surpassed. It should be here noticed that the shaft that was made the subject of experiment was broken through the culpable negligence of the attendant engineer. But the tabular results on the tensile power of steel are not invalidated by this fact.

"It appears, from these experiments, that the average ultimate tensile resistance of the steel in the shaft, excluding the specimens previously injured by the fracture, was 95,221 lbs. (42½ tons) per square inch—a resistance practically the same as that offered by Bessemer steel rails. But the rate of elongation of the steel in the shaft averaged 12·6 per cent.; and if we exclude, as we may fairly do, the specimens which broke at the head before the full strain came upon the metal, the mean elongation would be 14·7 per cent., whilst, it may be remembered, for steel rails we found the rate to be 9⅝ per cent.; hence, with the same ultimate strength in both instances, the steel in the shaft had the advantage of additional toughness, and, consequently, greater capability of resisting rough usage. The *elastic* resistance to tension, as indicated by these experiments, averaged 19 tons per square inch, which is a rather low fraction of its ultimate resistance, as compared with that obtained in other experiments on various makes of steel; but the fact is, the exact point at which the increments of extension cease to become regular is so difficult to determine, that unless the appliances at hand are of the same refined nature as those Mr. Kirkaldy (who tried the experiments) has at his disposal, the results of such delicate tests are not to be implicitly relied upon.

"The experiments on the resistance to compression support the conclusions, already drawn from previous ones, as to the practically unlimited extent to which weight may be piled upon a short column of steel without effecting its positive destruction. Thus, in these experiments the enormous stress of 98 tons per square inch merely entailed a depression of 36·1 per cent. in the specimens, and no doubt, as the area resisting the thrusting would have increased with the depression, a very much greater load might have been brought to bear had it been considered necessary."

It is almost needless to add, that any experiments on the tensile power of metals have many points that must remain unsatisfied. To our practical readers it will be no new fact that fresh circumstances require fresh trials. The want of homogeneity in all metals renders tabular statements of limited use. It is not in the power of man to follow entirely the perfections of nature. Our machines, beautiful and comparatively complete as they are, must still be reckoned only as approximations to that which is needed. If a piece of iron or steel be placed in the rolling-mill, the chances are that any imperfections *may* be detected and removed; but there is the chance that such imperfections may not be discovered: they may be, indeed, entirely lost sight of. Not long ago, we had occasion, professionally, to examine a boiler that had been tested by hydraulic power. This test it stood well, but still a very serious flaw existed in one of the plates, that might have led to the most serious consequences. So, in every case, our tests of the tensile power of metals must be considered as by no means to be thoroughly depended on.

TABLE A.—*Resistance to Extension, Set, and Rupture under Tensile or Pulling Stress, &c., of Steel described on the previous page.*

Test	Original.		Stress in Pounds per Square Inch.—Length of Specimens for Extensions 8·5 Inches.—Extension and Set, Inch.																	Ultimate Stress.		Fractured.				Stress.	Extension.	
																								Difference.				
No.	Dia.	Area.	40,000	44,000	48,000	52,000	56,000	60,000	64,000	68,000	72,000	76,000	80,000	84,000	88,000	92,000	96,000	100,000	104,000	Total.	Per Sq. Inch of Original Area.	Dia.	Area.	Area.	Per Cent	Per Square Inch of Fractured Area.	Total.	Per Cent.
	inch.	sq. inch.																		lb.	lb.	in.	sq. in.	sq. in.		lb.	in.	
743	1·25	1·2271	·043	·049	·069	·100	·128	·154	·188	·217	·250	·288	·330	·377	·435	·505	·590	·715	·913	128,420	104,642	—	Broke at the head			—	0·78	9·2
		Set			·013	·030	·049	·078	·091	·120	·148	·182	·218	·253	·312	·364	·451	·568	·740									
739	1·25	1·2271	·047	·051	·071	·102	·130	·160	·190	·228	·268	·310	·364	·417	·482	·570	·700	·895	...	126,940	103,447	1·11	0·9677	·2594	21·1	131,177	1·36	16·0
		Set			·017	·040	·062	·088	·111	·140	·174	·213	·262	·310	·370	·453	·574	·770										
741	1 25	1·2271	·046	·050	·068	·104	·132	·162	194	·236	·276	·316	·371	·426	·494	·586	·709	·896	...	126,680	103,235	1·12	0·9852	·2419	19·7	128,583	1·26	14·8
		Set			·014	·044	·061	·087	·116	·146	·179	·241	·266	·316	·374	·458	·572	·764										
755	1·25	1·2271	·044	·069	·097	·126	·158	·192	·230	·278	·320	·373	·432	·508	·600	·730	·924	...	...	121,080	98,671	1·13	1·0029	·2242	11·3	120,729	1·16	13·6
		Set		·019	·041	·065	·091	·121	·152	·183	·230	·275	·333	·398	·490	·612	·810											
760	0·75	0·4417	·041	·078	·100	·131	·160	·193	·233	·272	·327	·378	·450	·530	·648	·852	1·36	...	...	42,576	96,391	0·66	0·3421	·0996	22·5	124,455	1·29	15 2
		Set		·029	·050	·077	·092	·127	·158	·193	·244	·291	·360	·435	·552	·733												
753	1·25	1·2271	...	...	...	...	..	...	...	...	...	...	...	...	...	...	...	...	...	117,340	95,624	1·12	0·9852	·2419	19·7	119,102	1·16	13·6
761	0·75	0·4417	·032	·067	·091	·122	·153	·185	·222	·264	·320	·370	·455	·540	·660	·907	...	...	...	41,748	94,516	0·66	0·3421	·0996	22·5	122,034	1·23	14·4
		Set		·024	·043	·070	·093	·120	·153	·189	·237	·283	·366	·449	·568	·805												
747	1·25	1·2271	·041	·070	·095	·126	·164	·199	·241	·382	·334	·403	·465	·560	·710	·967	...	...	...	115,096	93,795	1·11	0·9677	·2594	21·1	118,939	1·03	12·1
		Set		·027	·044	·070	·095	·130	·165	·203	·247	·305	·368	·463	·603	·869												
757	1·25	1·2271	...	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...	...	114,880	93,619	1·09	0·9332	·2939	24·0	123,103	1·26	14·8
759	0·75	0·4417	·044	·085	·108	·138	·168	·202	·245	·287	·340	·411	·470	·573	·715	·980	...	...	..	41,004	92,830	0·65	0·3318	·1099	24·9	123,580	1·17	13·8
		Set	·010	·040	·061	·085	·110	·141	·180	·216	·267	·330	·391	·483	·618	·890												
762	0·75	0·4417	·046	·078	·107	·134	·165	·198	·243	·287	·340	·400	·482	·582	·730	1·03	...	...	...	40,848	92,479	0·65	0 3318	·1099	24·9	123,110	1·20	14·1
		Set	·011	·038	·060	·082	·105	·137	·174	·218	·262	·320	·400	·495	·631	0·95												
745	1·25	1·2271	...	...	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...	112,210	91,442	—	Broke at the head			—	0·87	10 2
751	1·25	1·2271	·064	·094	·125	·160	·192	·240	·285	·345	·418	·495	·600	·772	...	...	...	...	...	107,896	87,928	1·08	0 9161	·3110	25·3	117,788	1·39	16 4
		Set	·023	·045	·073	·101	·135	·172	·210	·262	·330	·409	·505	·670														
735	1·25	1·2271	·065	·098	·130	·164	·203	·250	·304	·373	·448	·544	·700	·103	...	...	...	...	...	103,656	84,472	1·07	0·8992	·3279	26·7	115,276	1·47	17·3
		Set	·024	·048	·075	·105	·140	·182	·230	·291	·366	·450	·602	·094														
																		Mean	95,221			Mean	22·6	122,322	Mean	14·0
737	1·25	1·2271	·046	·073	·100	·127	·163	·195	·235	·283	...	...	...	...	...	...	...	...	...	88,240	71,909	—	Broke at the head			—	0·32	3·8
		Set		·020	·041	·065	·093	·124	·153	·195												Previously cracked in connexion with the breakage.						
749	1·25	1·2271	...	...	...	...	...	...	...	...	..	...	...	...	...	...	...	...	...	86,820	70,752	—	Broke at the head			—	0·17	2·0
		Mean	·046	·072	·097	·128	·160	·194	·234	·279	·331	·391	·465	·574						Mean	92,235			Mean	22·6	122,322	12·6	12·6
		Mean Set	·005	·024	·044	·069	·093	·124	·157	·196	·244	·298	·370	·474														

TABLE B.—*Resistance to Torsion, Set, and Rupture under a Twisting Stress. Length for Torsion = Two Diameters.*

Test No.	Original. Dia.	Original. Area.	Length of Lever, 12 Inches.—Stress in Pounds on each end.—Torsion, One Turn = 1000. 700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	Ultimate Stress. On 12-inch Lever. Total.	Ultimate Stress. Per square in.	Ultimate Torsion.	Remarks.
																											lb.	lb.	Turn.	
742	1·25	1·2271	·001	·002	·003	·005	·007	·010	·013	·018	·024	·030	·035	·040	·046	·055	·070	·080	·086	·096	·116	·140	·173	·221	·282	·371	3006	2449	{0·386 0·463	1st end, fractured. 2nd end, nearly do.
		Set					·004	·006	·010	·015	·019	·023	·030	·035	·041	·049														
738	1·25	1·2271	·001	·002	·002	·003	·005	·008	·011	·015	·019	·025	·029	·036	·041	·050	·064	·078	·091	·112	·127	·145	·206	·254	·345	...	2928	2386	{0·376 0·398	1st end, fractured. 2nd end, nearly do.
		Set					·002	·004	·007	·012	·015	·020	·024	·030	·034	·046														
746	1.25	1·2271	·000	·001	·002	·004	·006	·008	·012	·017	·023	·029	·038	·046	·050	·067	·080	·098	·122	·145	·170	·214	·250	·345	...	...	2891	2356	{0·432 0·468	1st end, fractured. 2nd end, nearly do.
		Set					·003	·005	·009	·014	·020	·025	·033	·041	·044	·061														
750	1·25	1·2271	·000	·001	·002	·003	·010	·015	·021	·029	·035	·041	·052	·064	·084	·100	·122	·151	·198	·250	·360	·472	...	...	...	...	2628	2142	{0·495 0·508	1st end, fractured. 2nd end, nearly do.
		Set					·008	·013	·019	·025	·031	·037	·048	·060	·077	·094														
		Mean	·000	·001	·002	004	·007	·010	·014	·020	·025	·031	038	·046	·055	·068	·084	·102	·124	·151	·193	...	...	...	...	...	Mean	2333	0·441	
		Mean					·004	·007	·011	·016	·021	·026	·034	·041	·049	·062														

TABLE C.—*Resistance, Deflection, Set, and Rupture, under a Transverse or Bending Stress. Distance, Ten Inches.*

Test No.	Dimensions.	$B D^2$.	Stress in Pounds per $B D^2$.—Deflections and Sets, Inches. 1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10,000	10,500	11,000	11,500	12,000	Ultimate. Deflection.	Ultimate. Stress.	Ultimate. $\frac{\text{Stress}}{B D^2}$	Value of S. $S = \frac{L W}{4 B D^2}$
	Breadth. Depth.																												
740	1·37 × 1·76	4·2437	·019	·024	·029	·033	·038	·043	·048	·054	·061	·080	·104	·132	·170	·209	·253	·307	·376	·441	·518	·603	·711	·853	1·09	1·16	51,668	12,175	30,438
		Set											·030		·087		·171												
744	do. do.	4·2437	·022	·028	·036	·042	·049	.052	·057	·067	·081	·104	·133	·164	·198	·239	·280	·341	·392	·450	·529	·610	·729	·889	...	1·26	50,792	11,969	29,922
		Set									·017		·062		·116		·187												
754	do. × do.	4·2437	·023	·026	·031	·036	·041	·045	·050	·060	·082	·110	·146	·184	·225	·272	·322	·379	·442	·527	·660	·752	·913	1·17	...	1·46	50,288	11,850	29,625
		Set									·016		·074		·134		·222												
736	do. × do.	4·2437	·017	·021	·025	032	·039	·044	·050	·068	·090	·124	·166	·208	·252	·308	·360	·435	·520	·618	·762	·961	1·45	...	...	1·63	47,460	11,183	27,958
		Set									·023		·092		·156		·255												
752	do. × do.	4·2437	·021	·026	·031	·038	·046	·050	·054	·078	·110	·150	·193	·240	·288	·343	·407	·471	·578	·692	·850	1·05	1·61	...	...	1·73	47,312	11,149	27,872
		Set									·047		·120		·201		·310												
756	do. × do.	4·2437	·017	024	·031	·035	·040	·045	·050	·073	·106	·147	·190	·238	·297	·350	·418	·502	·602	·740	·892	1·10	1·66	...	...	1·77	47,028	11,082	27,705
		Set									·042		·112		·205		·315												
748	1·37 × 1·71	4·0460	·015	·021	·027	·030	·035	·041	·050	·070	·102	·143	·194	·249	·310	·365	·460	·540	·660	·828	1·02	1·41	...	...	...	1·53	42,872	10,702	26,755
		Set									·040		·118		·217		·353												
758	1·37 × 1·76	4·2437	·015	·021	·027	·032	·037	·052	·075	·108	·153	·200	·250	·313	·373	·455	·545	·657	·799	·974	1·27	...	...	...	...	1·41	44,376	10,457	26,142
		Set							·022		·085		·177		·282		·448												
		Mean	·019	·024	·029	·035	·041	·047	·054	·072	098	·132	·172	·216	·264	·318	·381	·454	·546	·659	·810	·927	1·179	..	...	1·49	47,725	11,321	28,302
		Mean									·034		·098		·175		·283												

TABLE D.—*Comparative Summary of the Results of Experiments on Pieces cut out of one of the Crank Spaces of Two New Wrought-Iron Shafts, made at Glasgow, for the Screw Steamship Jeddo, and on Pieces cut out of the Broken Crank of Cast-Steel Shaft, made at Essen, Prussia.*

IRON SHAFTS.					CAST-STEEL SHAFT.										
Pulling Stress.					Pulling Stress.					Bending Stress.		Thrusting Stress.		Twisting Stress.	
Ultimate Stress per Square Inch of Original Area.		Contraction of Area at Fracture.	Ultimate Stress per Square Inch of Fractured Area.	Ultimate Permanent Extension.	Ultimate Stress per Square Inch of Original Area.		Contraction of Area at Fracture.	Ultimate Stress per Square Inch of Fractured Area.	Ultimate Permanent Extension.	Ultimate Deflection.	Value of S. $S=\frac{L\ W.}{4\ B\ D^2}$	Ultimate Permanent Depression with 220,000 lb. per Square Inch.		Ultimate Stress. lb. per Square Inch on 12-in. Lever.	Ultimate Torsion.
lb.	lb.	per cent.	lb.	per cent.	lb.	lb.	per cent.	lb.	per cent.	in.		in.	per cent.	lb.	One turn=1·000.
49,671					104,642					1·16	30,438	·394	31·6		
47,591					103,447					1·26	29,922	·428	34·3	2,449	0·386 / 0·463
49,167	47,582	20·7	59,003	21·9	103,235					1·46	29,625	·433	34·7	2,386	0·376 / 0·398
45,234					98,671										
47,459					96,391										
46,450					95,624										
					94,516	95,221	22·6	122,322	14·0	1·63	27,958				
					93,795										
					93,619					1·73	27,872	·472	37·8	2,356	0·432 / 0·468
					92,830										
44,561					92,479					1·77	27,705				
44,311					91,442							·486	88·8		
43,420	43,759	23·1	56,910	20·5	87,928					1·53	26,755			2,142	0·495 / 0·508
43,420					84,472							·488	39 1		
43,420					71,909	71,330	...	...	2·9	1·41	26,142				
43,420					70,752										
Mean	45,670	21·9	57,956	21·2	Mean	92,235	22·6	122,322	12·6	1·49	28,302	·450	36·1	2,333	0.441

The experiments on the iron shafts were made by Mr. Kirkaldy, and the above results are from his published *Experiments on Wrought-Iron and Steel*, pp. 116, 117, 134, 135.

From the above table (D), it is evident that steel has, in every respect, the greatest advantage in regard to every test that can be applied to the tensile power of metals. It is therefore no matter of surprise that it is now applied to so many purposes; such as the building of steam-vessels, the construction of boilers, the framework of locomotives, &c., &c., subjects that will be dealt with in a subsequent chapter. But a few years ago, and under the old process of making steel, such applications would have been impossible, not only because of the cost, but also on account of the difficulties of making large masses of steel. Thanks to the Bessemer process, these difficulties are now entirely overcome.

CHAPTER IV.

COPPER, TIN, LEAD, AND ZINC.

IN the last chapter much space was devoted to a description of the various processes by which the ores of iron are converted into forms of enormous utility in our manufactures, &c. Special details of the latter will appear in a subsequent chapter, where the various uses of iron and steel, from the construction of the largest sized steam vessel to that of minute objects, such as the common needle, will be described.

But iron and steel have, at present, a limit to their uses. Thus an iron saucepan would, if it were untinned, be soon acted on by many liquids which contain acids, that would destroy the surface of the metal, and utterly spoil the contents of the vessel. This is partially got over by coating the surface with tin, which is not so easily acted on. Enamelling and galvanising (a method which we shall subsequently explain) have also been employed to protect the iron surface, hence our iron saucepans, frying-pans, "coppers" for boiling clothes, water-tanks, &c. But these iron vessels have a tendency to "burn," that is, partly to char the contents. Iron, again, is comparatively a bad conductor of heat, hence thick iron vessels, such as have been mentioned, cannot be used for many purposes. Copper conducts readily, hence its employment for stills for the distiller of spirits, boilers for the brewer, boiling and evaporating pans for the sugar-refiner, and in our households for kettles, preserve pans, &c. The various uses of tin, lead, and zinc will be pointed out as we proceed.

Copper and tin are metals that have been as long used by mankind as any other, and for as great a variety of purposes. The earliest history speaks of their use; and, in more modern times, we find that wherever copper can be readily obtained, especially in its native state, it is put to numerous uses by the countries, civilised or uncivilised, in which it may be discovered. The Esquimaux, for example, make numerous articles from it; as the specimens of productions, in the shape of knives and other cutting instruments, deposited as the collection of Arctic travellers, may be judged of in our national institution, the British Museum.

The uses to which copper has been applied, especially in olden times, denote, that next to the precious metals, gold and silver, it was most esteemed. In the pages of the earliest books of the Old Testament "brass" is frequently mentioned. In later periods we find accounts of numerous vessels, mirrors, and domestic utensils of copper or brass, or copper alloyed with tin; and the remains of Pompeii, Herculaneum, and other cities both in Greece and Rome, have afforded such interesting relics —not to mention copper coin, which, of Roman origin, is so abundant even in our day, as collected by antiquarians, that it fetches a price not much beyond its modern intrinsic value by weight. A mirror was found, during the last century, the metal of which consisted of an alloy of copper and tin, its locality being the ancient Brundusium. (See p. 112.)

The modern uses of copper and tin, separately and allied, and their almost simultaneous mining position in this country, have induced us to combine their consideration in most respects. In England, Cornwall is the chief place where both copper and tin mines exist; and, so far as this country is concerned, we may consider that county, and Devon, as the only places of importance for mining of both of these metals. But of late years the mining industries of both copper and tin have been seriously affected by foreign and colonial competition. At present we receive enormous supplies of copper in the form of bars from Australia and Chili, and of tin from the Dutch Settlements in the East Indies, imported here under the names of the Straits, Banca and Billiton, which effectually and ruinously compete with the produce of our mines. Indeed the latter have at times been almost denuded of late years by the emigration of the miners to other countries.

Native copper, all but unmixed with any other substance, and frequently entirely free from admixture, occurs in many parts of the world, and yet is confined to comparatively narrow limits wherever found. It occurs in veins, or beds, through rocks of most formations. Cornwall and Waterford, in our islands; Hungary, Spain, Sweden (Fahlun), and some parts of Germany; Siberia, China, and Japan; with Australia, Asia, and several parts of North and South America, possess native copper. Australia, and certain parts of the United States, from which we have seen specimens of a ton weight, and perfectly sectile, requiring only melting to fit it for commercial purposes, may be especially noted as affording it. But the greater portion of copper obtained is derived from ores, in which it is found combined with other substances, and especially sulphur, in which form it is recognised as copper pyrites, containing also a portion of iron. *Redruthite* is a sulphide of copper, or a union of copper with sulphur, and is a valuable and rich ore of copper. *Bornite*, a combined sulphide of copper and sulphide of iron, is a

valuable ore. *Towanite* has a chemical character similar to the preceding, and is an important ore. It is also used to afford blue vitriol, or sulphate of copper. Amongst the oxides of copper, *Cuprite* may be mentioned, which, when found in quantity, is a valuable ore. Carbonates of copper are of frequent occurrence. The blue carbonate, also called *Azurite*, &c., occurs in veins with the green carbonate. It has a beautiful blue colour. It is also called *Chessylite*, from being found at Chessy. In this country it is obtained in Cornwall, Cumberland, Scotland, &c.; and also in the Tyrol, and other parts of Austria, Siberia, Chili, and in certain districts of North America. When abundant, it is a valuable ore of copper. The most beautiful ore, however, is that known as *Malachite*, which is the green carbonate of copper. It occurs in Cornwall and Wales; in the countries just named, as possessing the blue carbonate; and in Australia. Malachite has been divided into the fibrous and massive. The crystallised variety is extremely rare, and only found in minute transparent twin-crystals, coating the cavities of the fibrous kinds. It is a valuable ore of copper; but is most prized by the lapidary on account of the beauty of its colour, and the high polish of which it is susceptible. The valuable vases and tables of malachite, manufactured at St. Petersburg, are mostly formed of thin plates of this substance, skilfully veneered. The high prices that good specimens obtain for such purposes, render this ore too expensive for smelting. There are other combinations of copper, as with arsenic, &c., forming ores; but these are of little, if any, commercial importance, with exceptions we shall subsequently notice when describing the method of smelting copper ores. Arsenic and oxide of iron are frequent constituents of copper ores.

The most important ore of tin is the binoxide, known, mineralogically, as *Tin-stone, Cassiterite, Oxide of Tin*, and *Pyramidal Tin Ore*. It occurs in veins, beds, and the drifts of streams. In this country Cornwall is our tin-mining district; but the purest tin is obtained from Malacca. Cassiterite occurs also in Sumatra, Siam, North and South America, and in many parts of continental Europe. In the days of the Phœnicians, Cornwall was noted for its tin ore; and those astute traders for a long time kept to themselves the secret of the source of this metal. The trade subsequently fell into the hands of the Greeks; and, at last, the Romans: so that tin-mining may be reckoned as one of the oldest branches of the art (see p. vi. in our introductory remarks).

At p. 43, and following pages, we have already given an account of most of the leading features of copper and tin-mining, in respect to the pits, mode of access, pumping water from the bottom, appearance, and other general particulars. It will therefore be unnecessary for us to enter again into the consideration of such details.

There are many methods of seeking for tin and copper ores, depending on the locality in which they are likely to be found. Some of these we have noticed: as, for instance, the sinking of a shaft, when, by chance, a vein or bed of copper may be hit upon. Another method, common in Cornwall, is that called *costeaning*, which consists of sinking small pits in various directions, from the surface to the solid rock beneath; and by then proceeding or cutting horizontally from one to another, the intersection, and consequent discovery of the metallic vein, will most probably be arrived at. Drifts are often run across a country where metallic veins are known or believed to exist. But this method, whilst occasionally successful, is as likely to fail.

Another plan, that seems more scientific in its character, because it proceeds in its adoption from observing certain facts, is that of *shoding*. It was formerly confined to the search for tin-stone; but now has a much more extensive application. It depends, in principle, on the fact, that the motion of water in a current, acting on a vein, will carry masses of it to a distance dependent on their weight or specific gravity. Thus we know that the stream-force of an ordinary river is sufficient to carry, to a long distance, fine particles of mud, sand, &c.; and the deltas of many of the largest rivers in the world have been thus formed, as at the mouth of the Nile, &c. Even the Thames is constantly producing similar results at its mouth. But during the course of the stream-current, pebbles, large pieces of stone, and rocks, are successively carried to less distances. Now, applying the same principles and facts to finding mineral bodies, it will be at once perceived that light masses of tin-stone will be found furthest from their original bed or source; and, between the two, heavier masses will be discovered; hence, by proceeding from the spot where the lighter pieces were first found, and tracing the course of the stream that removed them, at last the vein may be arrived at. This method is called *shoding*.

The following account of this plan is extracted from Bryce's *Mineralogy of Cornwall (Mineralogia Cornubiensis)*.

"When the miners find a good stone of ore or shode in the side or bottom of a hill, they first of all observe the situation of the neighbouring ground, and consider whence the deluge could most probably roll that stone down the hill; and, at the same time, they form a supposition on what point of the compass the lode takes its course; for if the shode be tin or copper ore, or promising for either, they conclude that the lode runs nearly east and west; but if a shode of lead ore, they have equal reason to conclude that the vein goes north and south. After finding the first stone or shode, they sink little pits as low as the first rubble (which is the rubble or clay never moved since the flood), to find more such stones; and if they meet with them, they go further up the hill in the same line, or a little obliquely perhaps, and sink more pits still, while they find shode stones in them; but they seldom sink those pits deeper than the rubble upon the shelf, except they are near the lode. If the shode is found in vegetable soil, the lode

is not at hand; but if it lies deep, massy, and angular, it is a certain sign that the lode is not far off; more especially if the shodes are of a pyramidal or conical form, and the base or heaviest part of them lies pointing one way, it is both a sign that the lode is not far off, and that it is to be found opposite to the base or heaviest part of the stones.

"As they advance thus nearer the lode with these pits, they find the shode more plentiful and deeper in the ground; but if they chance to go further from the lode, or pass the yonder side of it, there is a greater scarcity of the shode, or perhaps none at all; in which case they return to their last pit, which produced shode most plentifully, and work the intermediate ground with more care and circumspection, by drifts from one pit to the next, until they cut the lode. Sometimes they find two different shodes in the same pit at different depths; then they are sure that there is another lode further off; and in training up to the second they may meet with the shode of a third. However, when they are just come to the vein they set out for, they find an uncommon quantity of shode stones, answering to the description before given; and then they say that they have the *bryle* of the lode; upon which they dig down to the solid hard rock, which has never moved or loosened, until they open the lode, aud find its breadth by the walls in which it is enclosed."

Whatever success may occasionally attend any or all of the methods described, the result is more often accidentally than certainly arrived at. Gold-mining in Australia, California, &c., is conducted on similiar plans—with this difference, however, that the vein of gold is rarely reached, that metal being found in detached masses, from grains to nuggets, lying in the bed of an old stream, but seldom leading, by this method of shoding, to its original bed, vein, or lode.

At p. 44, *ante*, and following pages, will be found illustrations of metal mines and veins; the latter being represented by Figs. 82 and 83. In Fig. 84, p. 46, the "faults" of metal veins are shown; and this cut, to a great extent, illustrates the numerous difficulties that must necessarily be met in seeking for copper, tin, or lead in any district, unless previous experience has pointed out the general run of the lodes.

Tin, copper, and lead ores greatly differ in their character from those of iron, as already described; and hence they require other modes of treatment. The first step is that of dressing the ore after it has been brought to the surface of the ground. At every mine there is a large number of surface workers; amongst whom may be seen some men; but the majority of them are women and boys. They constitute from one-fifth to one-fourth of the whole number employed in and about the mine. These surface-workers are almost all in the pay of the tributers or under-ground men. It is their business to take the ore as it comes from the shaft; to have it stamped, cleaned, and washed, and prepared for the smelters. The larger masses are broken with hammers, generally by women, until the whole pile is in pieces of about the size of a large egg. If the ore be very rich it is then carried to the rollers, between which it is crushed. It is then ready for the market. This applies only to the copper ore, which is considered good if it have from 10 to 15 per cent. of metal in it. The preparation of tin ore is very different. It often comes to the surface with no more than 6 per cent. of metal in it; but before it is ready for market, and in a fit state to be received by the smelters, it has to be "worked up" until it contains 75 per cent. of metal: in other words, the great bulk of the dross must be got rid off. The ore is first taken to the stamper. As the crushed ore passes from the stamper it is carried by water to the beds, which slightly decline towards one end. The best part of the ore sinks immediately at the upper end of these beds, the dross not sinking until it reaches the lower end. This dross, still containing some metal, is again washed by being divided into other beds similarly situated; and the process is resumed until little but dross remains. In this way the tin ore is worked up to the requisite quality of 75 per cent.

When the copper ore is not very rich it is also put under stamp, and undergoes the process of washing. There are other operations, such as "jigging," &c.—all having in view the preparation of the ore for market. It is when sold, after it has been so prepared, that the tributer's earnings are determined; in ascertaining the net amount of which, he has, of course, to deduct the wages of those employed by him on the surface for the preparation of the ore.

It will be thus seen that there are numerous causes that increase the cost of copper and tin ores, that are not incident to those of iron. In the first place we notice that they are much poorer; for whilst the iron ores of this country generally average 31 per cent. produce in metallic iron, not simply per-centage on the ore, the copper ore rarely exceeds 15 per cent.; and tin more usually is as low as 6 per cent.

Lead is a metal abundant in many parts of this country, and it is applied to many useful purposes; for it is easily soldered together, drawn, bent, or rolled, although it has little tenacity. It has another advantage, which is that of ready fusibility by ordinary means, a common house-fire affording quite sufficient heat for the purpose. Its point of fusion, indeed, is below that at which mercury boils, varying from 600° upwards. It has the advantage of also long resisting the action of air and moisture, with an exception in regard to the latter, that we shall subsequently notice when we refer more especially to the chemical relations of copper, tin, and lead.

It is stated to have been found native in some parts of our own country, as at Alston, in Cumberland, &c.; but, like all other common metals, such a condition is too rare to allow of any supply for manufacturing purposes being derived from such a source. The chief ore of lead is *Galena*, in which the metal is allied with sulphur, forming a sulphide analogous to those of copper and iron. In this condition it occurs

abundantly in rocks of limestone geological formation. In these islands, Derbyshire, Yorkshire, Cumberland, Durham, Northumberland, Devonshire, Flintshire in Wales, and Lanarkshire in Scotland (especially Leadhills), are the chief localities where galena is procured. The same occurs also in several parts of continental Europe, America, &c. Many of the lead mines in Great Britain have been worked for a long time, at least dating from the period of the Romans. In Belgium an exceedingly rich mine occurs. France has also extensive sources of lead; and the same may be said of Prussia and Austria. Some states of the United States of America possess enormous deposits of lead, the full working of which would supply the demand of the entire civilised world. In numerous cases the lead is mixed with silver, the extraction of which is not simply a question of pecuniary profit, but a matter of necessity to the commercial value of the lead, which generally is brittle if most other metals are present in it—a question that we shall have eventually to deal with more in detail. There are other ores of lead than those we have described; but they are of no importance in relation to the production of the metal for commercial purposes.

The treatment of lead ore before smelting does not greatly differ from that of copper and tin already described; the object being to detach all other matters, and to reduce the ore into fragmentary portions. Lead ore, however, is generally, or, at all events, very frequently, obtained in masses so pure as to contain little or no earthy impurities, except at that part where it rests in the solid rock or matrix. On analysing a specimen of the ore from the mine, a visit to which we described at p. 42, *ante*, we discovered scarcely any constituent but sulphur and lead. Indeed, on boiling it in nitric acid, to convert the metal from a sulphide into a sulphate, the latter and a little sulphur, with no other precipitate, were obtained.

Fig. 115.—Ancient Metal Mirrors.

The largest lead mine worked in this kingdom we believe to be that of Allenhead, in Northumberland. Of this an excellent model was shown by the late Mr. Thomas Sopwith, in the London Exhibition of 1862. Dr. Ansted thus describes it, and the mode of preparing lead:—"In a thickness of about 2,000 feet of the alternating beds of sandstone, clay, and limestone, which form the strata of the mining districts of Allendale, Alston, and Weardale, there is one single stratum of limestone, called the 'great limestone,' the veins of which have produced nearly, if not quite, as much ore as all the other strata put together. Its thickness, which is tolerably uniform over several hundred square miles of country, is about sixty feet. In a great thickness of strata, *above* the *great limestone*, only two

beds of that rock are found. One of these is called 'little limestone;' it is from ten to twelve feet thick, and is seventy-five feet above the top of the 'great limestone.' The others are still more inconsiderable, being only three or four feet thick, and 440 feet above the 'great limestone.' Beneath the latter are several beds of the same description of rock—viz., at distances respectively of 30, 106, 190, 250, and 287 feet; and the thickness, 2, 24, 10, 15, and 35 feet. These are known by descriptive local names, and comprise all that are of significance as regards lead-mining operations.

"The Allenhead mines, being situated for the most part at depths from the surface varying from 200 to 600 feet, are drained partly by ordinary water-wheels, and partly by hydraulic engines, invented by Sir W. G. Armstrong. The lead raised in these mines amounts to about one-fourth part of the whole quantity raised in England, and one-tenth that of the whole of Europe.

"The produce of the mineral veins varies from pure galena, a sulphide of lead, to masses of rock or spar, in which the ore is so thinly disseminated as not to repay the trouble of extraction; and the process of preparing and dressing, after the extraction of the ore from its place in the mine, consists of the pure samples of ore being picked out, washed, and sized, ready for being smelted at once, without further operations; and also of the poorer samples being washed and separated, by an iron grate or sieve, into two sizes, the larger having to be ground between rollers, to reduce it to the same size as the smaller which has passed the grate. When reduced to this stage, the whole is ready for an operation called 'hotching.' This consists in placing the ore in a tub with water, the bottom of which tub is a sieve, and subjecting the whole to a rapid vibratory, vertical (up and down) movement, or shaking, by which a separation of the ore takes place. The water so far lessens the weight as greatly to facilitate the downward movement of the ore, which of course, is much heavier than the spar and other materials connected with it. The vibratory movement is sometimes given by manual labour: a long arm, moving with a spring, is jerked up and down by a strong lad jumping on a raised stand, so as to produce the required motion. The same results may be obtained by machinery. The ore being thus prepared and acted on, the uppermost part is entirely waste or refuse; and that at the bottom of the tub consists of ore ready for smelting. That which passes through the sieve requires clearing from foreign substances, and dressing, in a contrivance called a *buddle*, which is not unlike the hotching-tub above described.

"In all operations where a stream of running water is employed to wash lead ores, it is obvious that many of the smaller particles will be carried away with the stream. These particles are allowed to settle by their specific gravity, in what are called slime-pits, being merely reservoirs in which the water passes over a long space, with a very tranquil movement."

We have preferred to quote the preceding remarks rather than to give the results of a personal visit, made some years ago, throughout this district, and several of the lead-producing localities on the borders of Durham and Yorkshire; and therefore only add, that the methods just described are all but universal in the counties referred to. The neighbourhood of a lead mine, and the smelting erections, &c., bear a striking contrast to those of an iron district, whether as regards the extent or nature of operations. In fact, some lead localities that we have visited are so isolated, and, comparatively, on so small a scale, that both the mines and the smelting places would escape notice of all but those acquainted with the precise locality of their existence.

It does not follow, however, that a lead mine is an entirely innocuous neighbour. Many years ago, while temporarily residing with a relation, largely engaged in the manufacture of paper, in Yorkshire, it came out, in course of conversation, that when the water from the river was employed for making the pulp, and for other purposes connected with the manufacture, the paper assumed a dull appearance that no bleaching or blueing of the pulp could prevent. The causes of this was afterwards discovered. Higher up the stream the refuse of a lead mine, the washing of the ores, &c., ran into the river. They proved perfectly harmless to the trout, which were abundant in the river, but most probable the minute portion of lead insoluble, but held in suspension in the water, eventually became soluble, and so was conveyed into the paper. The water obtained from springs, &c., from adjacent hills, proved entirely free from this cause, and the paper made by it was of excellent colour.

So far we have traced copper, tin, and lead from the beds in which they are found, to their condition as prepared for the operations of the smelter, whose business it is, together with the operation of refining or purifying, to prepare the metals for use in commerce. We have observed that the sources and proximity of these ores connect them together materially in geological, mineralogical, and technical character or condition; and as we proceed, it will be seen that their chemical relationships, whether as ores, metals, or in their various uses in the arts, &c., do not dissever them in many respects. Whilst iron is chiefly esteemed and used as a metal, either by itself, or in the form of steel, copper, tin, and lead have far more extended uses. Independent of their individual metallic character, their alloys are of great value; as, for example, brass, bell, gun, bronze, and other "metals," pewter, solder, &c., &c. Their salts as blue vitriol, or sulphate of copper; verdigris, the acetate of copper; acetate or sugar of lead, chrome or chromate of lead; white and red lead, with litharge; the chlorides of tin, or "spirits" of the dyer, are but a portion only of the numerous conditions in which these metals become of extended use when combined with other bodies. These applications arise from their various chemical characters, and the readiness with which each of them enters into com-

pounds with other bodies. Thus the oxidation of lead by heat produces red lead, and litharge; massicot and minium, with red lead, are all oxides of the metal. The carbonate is the white lead of commerce; and each and all of these compounds are largely used as pigments for the use of the painter; and one, at least (litharge), for producing the drying oil used in varnish-making.

Much, however, as they may agree, generally, in the conditions just spoken of, great difference arises in those of a physical character. In colour, copper is the only red metal we obtain; tin is one of the whitest; whilst lead inclines to blue. Copper is one of the most tenacious metals that we possess; whilst lead is the least so of any of the ordinary metals. They are all malleable and ductile; copper being especially capable of being drawn out into wire, rolled out into sheet, hammered, &c. Tin is never used by itself for any mechanical purpose, except as tin-foil, for it is too soft, and has too little tenacity for replacing any other metal for such purposes. As a coating for iron and copper plate, to preserve them from the action of air, moisture, and acid, and as an ingredient in solder, it is largely used. Lead, as a metal, is chiefly confined to the form of sheet, that is only used when it can be subject to neither strain nor motion; to the manufacture of lead piping, pewter, and solder, united with tin. Formerly it was much used for lining cisterns and covering roofs; but in both of these applications it has been greatly superseded by zinc, which, with far less thickness and comparative weight, is readily adaptable to all such purposes. A great objection to the use of lead as a lining for cisterns is, that although if the water stored in it be hard, having soluble sulphates, no harm can arise; yet if soft water be so kept, a carbonate of the metal will form at the junction of the air and water-line. The carbonic acid in the water will gradually dissolve this, and so form a solution of great danger to health, and productive of fatal results, by what is therefore designated as lead-poisoning. Copper as already stated is acted upon by many liquids employed in culinary operations; hence the absolute necessity, for safety's sake, of having it coated with tin. But if a portion of this be rubbed off the copper surface, and some saline substances—as, for example, a salt ham—be boiled in a copper vessel in such a condition, the danger is augmented, for the negative state of the tin renders the copper still more positive; or, in other words, hastens the solution of the copper, and increases the danger of its use. Preserving-pans, coppers, soda-water machines, and similar vessels made of copper, may therefore, without proper precaution, become exceedingly dangerous. We must, however, for the present defer the consideration of the chemical condition of each of these metals, and their alloys, until the methods of reducing their ores, and preparing the metals, have been described.

Before doing so, however, a few remarks may be made on the methods of analysing, qualitatively, ores suspected to contain any of the metals—copper, tin, and lead. We do not propose giving directions in respect to quantitative analysis, simply because it requires considerable experience to carry on such an operation with the ores of copper and tin; whilst, although that of lead may be arrived at, for approximative purposes, by a little variation of the ordinary method of smelting the galena, or by boiling it in nitric acid to convert the sulphide into the sulphate, as already mentioned, still the most important part of a lead ore analysis—that is the detection of copper or silver present—is by no means an easy task to those unaccustomed to laboratory processes, and chemical manipulation generally.

The ordinary ores of copper—that is, the sulphides and carbonates—are readily soluble in warm nitric acid, affording the characteristic colour, blue, of the nitrate or sulphate of copper, these salts having that colour. If, however, the amount of copper be small, so as to give a slight blue tinge, the addition of liquid ammonia will detect its presence by affording a rich blue transparent solution if added in excess. At the same time any iron present will be precipitated as oxide, and eventually settle to the bottom of the vessel. If a solution of ferrocyanide of potassium (the yellow prussiate of potass) be added to any liquid containing copper in solution, a brown or mahogany-coloured precipitate of the same salt of copper will be thrown down. A clean steel or iron polished surface, introduced into a slightly acid solution of copper, affords a precipitate of the latter metal on the iron surface. By the latter plan a rough quantitative analysis of a copper ore, so far as the copper alone is concerned, may be made. The ore is dissolved in nitric acid, and, on the solution being effected, it is heated until *all* free acid is dispelled. A piece of clean zinc or iron is then to be put into the vessel, when either of the two latter will be dissolved away, and an equivalent of copper in the metallic state produced. When no more copper is thrown down, and none is contained in the liquid, which may be tested for it, sulphuric acid, diluted with five parts by weight of water, may be added. This will dissolve away all the zinc or iron, but leaves the copper untouched. The copper should then be filtered off from the liquid on a weighed filter, washed, and dried. After weighing, and deducting the weight of the filter from the gross weight, the remainder is the weight of the copper present in the ore. A very neat way of analysing a copper ore, is that of pouring the solution containing it into a vessel, in which a porous pot, containing a little sulphuric acid and water, is to be placed. In the porous pot a piece of amalgamated zinc is to be put, and, attached to it by a wire, a weighed clean piece of copper plate is to be suspended in the copper solution. After a time, nearly all the copper will, by electro-chemical action, be deposited on the copper plate, which should then be washed and weighed. Its increase, of course, will denote the amount of copper in the assayed solution. Fuller details of the principles on which this action depends, will be found

in the elementary description of electro-metallurgy, at p. 37 *ante*, and following pages.

Potash precipitates copper in solution as a hydrate, which turns black on being boiled. The solution, to be tested, should be hot and dilute. Copper and lead may be separated by dissolving the ore in nitric acid, and adding sulphuric acid. The sulphate of copper being soluble, will remain in solution; whilst the insoluble sulphate of lead will fall down as a white precipitate. Its separation from iron has already been indicated by the first test that we have suggested for its presence. But the precipitate thrown down by ammonia may be either the oxide of iron or that of aluminium (alumina). These are readily distinguished by filtering the precipitate, and washing it. The precipitate is then to be dissolved in hydrochloric acid, when both oxides will be held in solution. If caustic potass be added to this, the iron will be thrown down as an oxide; whilst the alumina will be retained in solution. But if, after filtering away the iron precipitate, a solution of sal-ammoniac be added to the clear solution, alumina, if present, will be thrown down. Thus iron, lead, and alumina may be discovered in ores of copper. The estimation of sulphur and arsenic we shall not enter into, as they require careful manipulation to afford anything like accurate results; and it will be sufficient for most of our readers to understand the simple plans and objects we have selected. At p. 54, *ante*, and following pages, we have given instructions for the analysis of iron ores; and the details there mentioned are equally applicable to analysis of the metals under present consideration.

The chief tin ore, the peroxide, is insoluble in acids, but becomes chemically tractable by fusing it with about three times its weight of the carbonate of potass or soda. It is thereby rendered soluble in acids. But it presents too many difficulties for all but the practical chemist to determine the amount of its presence in any ore. The reason of this will be at once seen on referring to p. 111, *ante*, where the usual poverty of tin ores, in their first stage, has been stated. Dissolved as a chloride, by the action of hydrochloric acid, or that mixed with nitric acid, the solution affords, as a protochloride, a highly characteristic precipitate, of a purple colour, when the perchloride of gold is added to it. From a solution of the protoxide of tin, hydrosulphuric acid (sulphuretted hydrogen in solution) gives a dark-brown sulphide; also produced by the hydrosulphate of ammonia. Caustic potass and ammonia afford white hydrates, the result of the first being soluble, and that of the last-named alkali insoluble in excess; and if protochloride of mercury be added to a solution of the protoxide, metallic mercury is reduced as a gray precipitate. Before the blowpipe, the protoxide of tin, on a charcoal support, with carbonate of soda and cyanide of potassium, affords a metallic bead of tin. The peroxide of tin gives a yellow sulphide with hydrosulphuric acid; the same with hydrosulphate of ammonia, but soluble in excess of this reagent; a soluble hydrate with potass; and the bichloride, with hydrochloric acid, is reduced by zinc. Under the blowpipe, the reaction is the same as afforded by the protoxide.

Galena, as lead ore, is most readily dealt with by boiling it for some time in nitric acid, the oxygen of which oxidises the sulphur, producing sulphate of lead as a white powder, as already mentioned. The sulphide is readily reduced, by heating it first on a charcoal support, by the blowpipe in the oxidising flame, to expel sulphur, &c. On then bringing the reducing flame to bear on it, a bead of metallic lead may be obtained. Lead, although forming salts with sulphuric and hydrochloric acid, is not susceptible of testing in either form. Its solvents are nitric and acetic acids, forming a soluble nitrate, and also a soluble acetate. Brought into solution it affords a black precipitate with either hydrosulphuric acid or the hydrosulphate of ammonia; a rich yellow precipitate with either the chromate or bichromate of potass; a white hydrate, insoluble in excess, with caustic potass; with hydrochloric acid, a crystalline chloride, barely soluble, and distinguished from that of silver by being insoluble in ammonia, which would separate the chloride of silver; the remaining chloride of lead being unchangeable by light, while that of silver turns black on exposure to light. The blowpipe method is most eligible to detect lead; the fact of this metal present being verified by some or all of the tests here given. Nothing is easier, in fact, than the reduction of lead by the blowpipe, with a charcoal support; and, on a large scale, by first roasting and oxidising the ore by heat and access of air; afterwards making the oxide into a paste with charcoal-dust and oil, and heating the mixture to redness. A button of lead is thus readily produced.

The detection of silver in lead is by no means so easy to unpractised hands. Generally speaking, it is present in but small quantities, not exceeding from eight to thirty ounces of silver to a ton of lead, although a very large quantity of silver is yearly obtained in this country from the lead, by an ingenious process that we shall subsequently explain. Rarely the average amount of silver in lead is much beyond that above stated: such, however, is an exceptional case. If the lead and silver have been simultaneously extracted from a lead ore, which must first be done by reducing the metal, and subsequent solution in nitric acid, both metals form nitrates; and, on adding a solution of almost any chloride, as common salt, both metals will be precipitated as chlorides. The lead chloride being slightly soluble, may be gradually dissolved away by water. But this is a tedious process. A simple plan is that of washing the precipitate of both chlorides in water, and then digesting it in liquid ammonia, as already explained under the head of the detection of lead. The latter dissolves the chloride of silver, but not the chloride of lead. On adding hydro-chloric acid to the ammonia solution, the silver will again fall as chloride; and its presence may be assured by the white curdy precipitate turning black in daylight.

The reduction of copper, tin, and lead ores to the metallic state, although identical in character as chemical processes, varies much in the details. Generally the copper is associated with iron, sulphur, and arsenic; and the difficulty of reducing the metal lies in the pertinacity with which it adheres to these constituents of its ores. As already noticed, the copper ores produced in this kingdom, and imported from abroad, are all smelted in South Wales, in the neighbourhood of Swansea. Practically, we may consider all copper ores usually employed as sources of the metal to be sulphides; and hence the removal of the sulphur is an important operation, analogous to that required in dealing with galena, the sulphide of lead ore. But the latter presents much less difficulty; for by being roasted with coal, its sulphur is speedily driven off, and the reduction of the oxide thus produced is readily effected. Tin may always be considered as an oxide contaminated with earthy matter, other metals, and sulphur; but still the chemical principles of its reduction are simple: they are merely the removal of the oxygen of the oxide in the form of carbonic acid, produced by the union of carbon with the oxygen of the ore.

Of recent years great improvements have been made in the treatment of each of these ores after they have been prepared at the mine—as described for copper and tin, at p. 111, *ante;* and for lead, at p. 113, *ante;* the object being, in all cases, to diminish the cost of smelting, and, therefore, that of the produced metal. Formerly all the sulphur of the copper was dissipated in the atmosphere, spreading blightly fumes of sulphurous acid, united with arsenic vapours in all directions: now a large proportion of the sulphur is retained by condensation in the solid form, or by so roasting the ores at some chemical works that the sulphur may be converted into sulphuric acid—a most valuable chemical production. Frequently a large quantity of iron pyrites is found as marcasite or mundic; and this is utilised, in connection with the production of copper ore from the mines, by being sold to the chemical manufacturers for the production of sulphuric acid by the oxidation of the sulphur in the manner just mentioned. Another source of profit in working a copper mine, is occasionally found in the solution of sulphate of copper that runs from some of them. Acting on the principles detailed at p. 114, *ante*, for one means of analysing a copper ore—by putting into its solution a piece of zinc or iron, and so effecting the reduction of the metal—great quantities of old iron pots, pans, &c., are sent from London to such mines; and being thrown into the solution of copper salt, the latter is decomposed at the expense of the iron, the sulphuric acid attaching itself to the latter to form copperas or sulphate of iron, and depositing pure copper as a brown powder, that only requires to be melted and rolled to fit it for commercial purposes, as sheet copper. In every branch of metallurgy, in fact, the great competition that exists at the present day, stimulated by cheap means of transit, necessitates the most careful application of chemistry in each of the processes that the ordinary metals have to undergo in the reduction of their ores, refining, &c.

Here we may notice a recent and great improvement which has been invented in dealing with ores containing sulphur and consequently being sulphides. Mr. John Hollway, of London, has succeeded in developing a metallurgical process, having for its main object the utilisation of the heat obtained by the oxidation of certain mineral substances which have never before been utilised as sources of heat in smelting operations, such heat being made to take the place of carbonaceous fuel in the reduction of the ore. In view of the scarcity in some countries of ordinary fuels, and the co-existent abundance of mineral substances, such as pyrites, in which a large amount of this heat is conserved, this process possesses a wide interest and may ultimately have a very important bearing upon metallurgical science and practice, especially as regards the reduction of copper ores. The principle of the process consists in the oxidisation of sulphides, and the consequent development of a sufficient amount of heat to render their smelting a self-supporting operation, the only extraneous fuel used being a very small quantity of coke at starting, in order to give the necessary initial temperature in the same way that wood is used to light a coal fire. The practice consists in forcing a current of air through the molten sulphides, thus rapidly oxidising them, and causing a large proportion of the sulphur to be expelled in the free state, the resulting heat serving for the fusion of the cold ore without the addition of any other fuel. The first experiments which were undertaken in order to demonstrate the practicability of the invention were carried out by Mr. Hollway, at Messrs. Cammell and Co.'s Works, at Penistone, and at Messrs. John Brown and Co.'s Atlas Works, at Sheffield. It is those carried out at the latter works with which we propose to deal, and to place their particulars before our readers.

The first experiment at the Atlas Works was carried out in May, 1879, and the especial object then in view was to prove that in the smelting of cupreous ores a large proportion of the sulphur could be expelled in the free state, and be afterwards collected. At the same time it was also desired to demonstrate the fact that the ore under treatment contained the primary element of its own reduction, namely, sufficient heat. And here we must premise that the plant used is not that which has been made for this special operation, nor is it that which would be adopted in practical working, although the general principles would remain the same. It is simply a portion of a Bessemer plant, which has been rendered available by certain alterations being made in it. The plant is that in the Bessemer C shop at the Atlas Works, and consists of four ordinary cupolas modified to suit the requirements of the process, and marked A, B, C, and D. In cupola A the side tuyeres were removed, and a Bessemer hearth, with the necessary blast, substituted. At the side of this cupola, and in communication with it, is a

fore-hearth or receptacle, in which the regulus and slag are allowed to accumulate in a quiescent state away from the influence of the blast. This fore-hearth is about 3 ft. in diameter internally, and at the height of 6 feet 6 inches from the bottom is an outlet for the slag. The floor of the fore-hearth is about 2 feet below the level of the hearth of the cupola. The mixed regulus and slag flow over into this receiver, the regulus sinking to the bottom, and the slag rising, and ultimately flowing off at the outlet. The regulus is tapped at intervals from the bottom of the fore-hearth. In order to prevent the escape of the gases the cupola is fitted with a cup and cone arrangement for charging, similar to that used in blast furnaces. At a height of about 12 feet from the hearth in cupola A is a brick flue opening into cupola B, and through which the gases are conducted from the former into the latter. Cupola B is closed at the top, and has its lower charging door also closed, and within it is a jet of water which is forced from the bottom to the top. Here the gases are cooled, and the crude sulphur and other sublimates are condensed. The uncondensed portion of the vapour passes from the bottom of cupola B by a passage into cupola C, where it encounters a shower of water which further condenses the vapours. From C the remaining portion—if any—of the vapour is conducted to cupola D, where it meets another shower of water, and where still further condensation is effected. The two last cupolas have their charging doors closed, but their tops are left open so as to permit of the escape of the uncondensed gases which are here considerably reduced and attenuated. The water from the three cupolas is carried off through a culvert to a tank where any sublimates that may be carried over with it are collected.

In carrying out the first experiment cupola A was first heated with a coke fire and the blast started. Rio Tinto cupreous pyrites containing by wet assay 1·7 of copper, 48·0 of sulphur, and 42·0 of iron were then charged into the cupola with some charcoal until a fluid bath of molten sulphide was obtained. After this pyrites and sandstone were charged in without any other fuel at the rate of about five tons per hour. When a charge of about twelve tons had been thus accumulated, operations were brought to a standstill by reason of a deposit of sulphur having been formed at the bottom of the cupola B. This closed up the exit from B to C, and the imprisoned gases lifted the top of cupola B, and by back pressure drove out the molten slag in a rapid stream from the fore-hearth. The practical results of the experiment were, however, to a considerable extent attained. In the first place, it was demonstrated to the satisfaction of those present that the heat developed from the pyrites was more than sufficient for the melting of the charge, whilst in the second it was proved—too palpably perhaps—that the sulphur could be condensed from the vapours and afterwards collected in a free state. The copper and iron were moreover concentrated into a regulus of excellent quality.

The subsequent experiments at the Atlas Works were instituted with the view of showing that a good regulus could be obtained without great loss of copper in the slag, and were, like those by which they were preceded, conducted in the presence of many metallurgists and representatives of the copper trade and of American and other mines. The previous experiments having proved conclusive as to the collection of the sublimates, that point was not again demonstrated, the sulphur being allowed to burn to waste. The cupola A only was, therefore, used, communication between it and cupola B having been cut off. These experiments, however, were only partially carried out owing to defects developing themselves in the extemporised apparatus which was most persistent in giving way now here a little and now there a little, besides disclosing some inherent defects which could not well have been foreseen in adapting the old plant to its new work. All these circumstances combined to interfere with the continuity of the working. The object of the experiments, however, was gained, although not on the scale that was contemplated, inasmuch as the slag upon assay was found to contain only ·04 per cent. of copper. This points conclusively to the presence of the whole of the metal—save the above mere trace —in the regulus, which, in fact, was proved by assay. The value of the pyrites as a fuel was, moreover, repeatedly demonstrated during the experiments, which we may here mention will shortly be resumed. Upon one occasion, owing to insufficient feeding, the furnace was reduced to a very low state of activity. By the free supply of pyrites as a fuel, however, the temperature was rapidly raised, and the furnace restored to its normal working condition. Although the trials were not carried to their proper conclusion, the want of success in this respect is in no way chargeable to Mr. Hollway's process, as proved by the results of previous working. The main purpose for which fuel is required in this process is, of course, that of maintaining the blast, but in situations where water is available, steam would be unnecessary, and its expense would be avoided.

Generally speaking subsequent trials of the process under more favourable circumstances, have tended to prove its success, and it has met with the approval of some of the most eminent metallurgists and chemists.

Before entering on a description of some comparatively recent improvements in the reduction of copper, tin, lead and zinc ores, it may be desirable to give what may be called, in some senses, the old methods, although practically they are now in general use with the modifications afterwards to be alluded to. It is a maxim in applied science that nothing should be wasted, and indeed at the present day our rapid advances in many manufactures, especially in the treatment of metallic ores, are due not only to the prevention of waste, but of utilising what is generally called waste and which is unavoidable.

Copper ores, after being broken into pieces, as detailed at p. 111, *ante*, are roasted in a reverberatory furnace, so that as much as possible of the volatile ingredients are carried off, as arsenic and sulphur. The latter, as just pointed out, is now utilised to a considerable extent (see Hollway's process described at p. 116, *ante*). The roasting process is assisted by repeatedly stirring the ore, so as to expose it to the action of flame, and the hot air passing over it—the entire arrangement not greatly differing, except as regards the result, from that described and illustrated in respect to pig-iron. After as much as possible of volatile matter is driven off, the ore is transferred to a smaller furnace and fused, lime being added to form a flux for earthy and oxidised metallic matter in the form of impurity; the slag thus produced being constantly scraped off the surface of the metal. The fused metal is then run off through a tap-hole at the bottom of the hearth of the furnace; the whole operation somewhat resembling, but on a very small scale, the smelting of iron, as described at p. 64, *ante*. Whilst in a melted condition, the metal is suddenly cooled in water, so as to reduce it to a granular condition. To remove the sulphur and arsenic still persistently remaining, repetitions of these processes are followed, each successive operation affording fresh portions of slag for removal; but which, as containing some metallic copper, is reserved for subsequent and separate operation for its extraction. By these repeated processes the copper becomes gradually purified, and is then kept at a low red heat for some time, fused, and cast into ingots. In its early condition of the granular state, copper is recognised as "coarse metal;" and in each successive operation it becomes "calcined coarse metal," "fine metal;" and, in the form of pigs attains the name of coarse copper. By again roasting, and fusion, it is converted into "blistered copper;" the last process resulting in the production of "refined copper." In this condition it is introduced into commerce in the form of flat slabs, or cakes, to undergo the operation of rolling, &c. This is alternated with heating; the pieces are rolled out into greater width; and lengths being cut, again rolled and heated, until any desired thickness of sheet is acquired. But the operations of smelting and refining the copper conclude those carried on in South Wales, the cakes of refined copper being sent to the different copper-works throughout the country for conversion into sheet, foil, or wire.

As previously mentioned, the difficulty of smelting copper arises from the pertinacity with which it rests combined with the substance united with it in its ores. The general principles involved in the operation are—first, the removal of all volatile matter, as far as possible, by roasting; and, secondly, to take away the iron, often so abundantly present, by oxidating it, and dissolving the oxide with a flux, to form a slag. The remaining copper is generally mixed with some of its oxide towards the conclusion of the process; but this may be removed by adding powdered charcoal, and stirring the fused metal with a green wooden rod. The hydrocarbonous gases and carbon thus afforded, deoxidise the oxide of copper, and leave the metal tolerably pure. We may add, however, that nearly every specimen of copper in sheet, &c., will afford arsenic on careful chemical analysis.

The general process of the reduction of tin ores may next be described, as having been long practised. The ore, as broken into masses, mentioned at p. 111, *ante*, requires roasting before it can be smelted; and by this operation the oxide of tin becomes, to a considerable extent, freed from foreign substances. After washing, the oxide is next mixed with coal and lime, as a flux for earthy matters, and strongly heated, by which its deoxidation is effected. The liquid tin is then drawn off, and poured into moulds; being purified by subsequent processes of melting in a reverberatory furnace, and cast into blocks—hence called "block tin" in commerce. This process refers to the ore as raised from the mines. By thus roasting, the copper and iron present in the ore become oxidised, and the washing extracts a good deal of sulphate of copper, due to the oxidation also of the sulphur, resulting in the formation of sulphuric acid. The sulphate of copper so formed is utilised by throwing into it old iron, to precipitate metallic copper, as already explained at p. 116, *ante*.

But the purest kind of tin, called "stream tin," is that obtained from nodules or masses, spoken of at p. 110, *ante*, as found in beds of currents or streams, that, in their course, have washed it from the original vein; and which has also been alluded to in the description of the method of "shoding." (See *ante* p. 110.) These masses, after being broken up, are carefully washed, to free them from all adherent earthy matter; and, in a minute state of division, the ore is heated with charcoal in a blast furnace. The metal is gradually reduced, and then transferred to a large iron vessel, in which it is kept melted, pieces of charcoal being thrown in to reduce any remaining oxide, and to clear off slag that will arise. After being poured into moulds, this forms the grain tin of commerce.

The smelting of lead ore is, perhaps, the most simple of all operations in metallurgy. It is first roasted like copper and tin ores, to drive off the sulphur; and afterwards put, either into a blast furnace (called also an ore-hearth), or a reverberatory furnace. In any case the oxide of lead is decomposed by the heat and the carbon of the fuel, to which is sometimes added lime as flux; and the lead is drawn off in a melted state, and cast into pigs. During this process the slag becomes fluid, like that of iron, copper, &c., and contains also some lead, which is subsequently smelted out by means of coke in a kind of blast furnace, called a slag-hearth; by which means the greater portion of the lead is recovered. The metal in pigs is, however, impure. It has especially to be freed from silver, which is generally present, and that, if left in the lead, would cause it to be very brittle. The ordinary method is that of re-melting the lead in large iron vessels, heated beneath by a

furnace, but open like a pan at the top. The lead is kept constantly stirred. On the mass being allowed to cool, portions of the metal fall to the bottom, being such as contain the least amount of silver in a crystal-like state. This portion is removed, and the process repeated until the lead left, becoming richer by degrees in silver, is removed, and subsequently submitted to the process of cupellation, which we shall describe in connection with gold and silver, at a future page. By this cupellation the lead is oxidised by the action of heat and atmospheric air, whilst the silver is unacted on. The red oxide of lead is formed; and beneath this the silver collects in a fluid condition, and thus the two metals may be completely parted. The litharge thus produced is reduced to metallic lead by the action of heat and coal, the carbon of which unites with the oxygen of the oxide, and sets the metal free. When describing the metallurgical processes connected with the production of silver, further details and modifications of these processes will be entered into.

Zinc is a metal entirely disassociated with the three preceding in its physical, chemical, and geological conditions; but as it and its ores are of great importance in producing brass with copper, we shall include it in this article; having kept it separate and last for the above reasons, and also because, in the preparation of the ore, and smelting of the metal, the processes entirely differ from those previously described.

There are two chief sources of zinc, of which but one is usually employed to obtain the metal. It is *Calamine*, a carbonate of zinc, and known to mineralogists also as *Zinc Spar*, *Rhombohedral Zinc Baryta*, and *Smithsonite*. This ore is found in slate, transition, coal, and oolite formations. Occasionally it is met with in Scotland, Cumberland, Somersetshire, and Derbyshire; but chiefly in Germany and Westphalia, Silesia, Carinthia, Poland, Hungary, Servia; some parts of France and Belgium; in the Altai Mountains, United States, &c. But a considerable deposit of calamine has been discovered in the carboniferous limestone of Ireland; and, in 1862, samples of this ore were, we believe for the first time, shown at the Exhibition held in London, sent by the General Mining Company of Ireland. The chief supplies of the metal, however, are derived from Germany, where there are many mines and smelting furnaces in full operation, immense quantities of the rough zinc, or spelter (as it is named in commerce, as imported in flat plates), being produced annually in that country. Extensive rolling establishments also are in operation in various parts of Prussia, whence much sheet zinc is exported. In the northern portion of Spain much calamine exists, from Santander to the Asturias, the mines being chiefly owned by French and Belgian proprietors; the Spaniards in this, as in almost all their metallic ores, except quicksilver, availing themselves but little of the enormous amount of metallic riches they naturally possess. The quantity of calamine is stated to be so abundant, as to be actually capable of being quarried like stone. In the British Isles the mining and smelting of zinc have not proved remunerative, although the metal is produced to a limited extent, or rather smelted, at Swansea.

Blend, the *Black Jack* of miners, a sulphide of zinc, is another source of the metal that is had but little recourse to, because of the difficulty that arises in smelting it. It is pretty widely diffused, being met with in veins and beds, in crystalline, slate, and transition rocks. In these islands it has been met with in Derbyshire, Cornwall, Flint, Perthshire, Leadhills in Lanarkshire, &c.: also in Sweden, Bohemia, Hungary, Saxony, Hartz Mountains, and other places. A native oxide exists, known by mineralogists as *Spartalite*, *Red Oxide of Zinc*, *Zincite*, or *Prismatic Zinc Ore*. It is usually of a red colour, whilst the artificial kind is always white; and occurs in beds with *Franklinite* and *Calcite*, in New Jersey (United States), and near Sparta, in Greece. It is also occasionally found crystallised in the iron and zinc furnaces of Silesia and Liège. It is of no value as a smelting ore, from its rarity.

Although zinc has long been known, its general application for commercial, domestic, and other purposes, is comparatively recent—so recent, in fact, that any of our readers who have entered the fourth decade of their lives, will remember almost its earliest general adoption in this country. In 1731, its price was £260 per ton; whilst, at the present day, it may be bought, as spelter in cakes, at about a twentieth of that price. Many reasons conspired to this result, and especially the difficulty that formerly existed in converting it into sheets; for it was not then known, that while brittle and non-malleable at ordinary temperatures, it becomes readily rolled into sheets, and beaten into thin leaves, at a temperature ranging from 250° to 300°. At a temperature of 400° it becomes again so slightly tenacious as to be readily pulverisable.

The method of smelting zinc is entirely different from that adopted in procuring any of the ordinary metals, except mercury; and both being volatilisable, the process of distillation is adopted. Various modifications of the operation are followed, but the principle is the same in all cases.

The ore is first picked and dressed like those of tin, copper, and lead; it is then roasted to drive off carbonic acid and water, in the case of calamine. Being afterwards washed, to separate matter lighter than the ore, and powdered, it is mixed with powdered coke, or preferably, charcoal, and packed in pots or crucibles. In the centre of the pot is a pipe, that reaches nearly to its upper rim, but descends through its lower end into a vessel of water. After the pot is filled with layers of ore and charcoal, it is covered so as to be air-tight. The pot is then placed in a furnace, and heat being applied, the zinc becomes reduced, and converted into vapour. As in this condition it cannot escape from the pot, except by means of the pipe, its vapour descends through this, and, on reaching the water, is condensed, affording the zinc in the form of various-sized globules. To purify it from arsenic, &c., it is again melted, and sul-

phur, with fatty matter, is thrown in, the latter to prevent the oxidation of the zinc, and the former to remove arsenic, iron, &c., as sulphides, which rise as scoriæ to the surface. The metal is then cast in flat cakes, in which condition it forms the spelter of commerce. The annexed cut, Fig. 116, will give an idea of the method of smelting zinc that has been just explained.

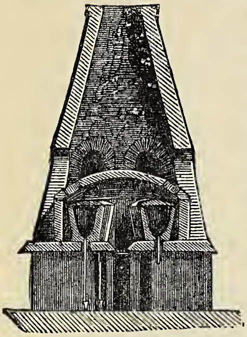


Fig. 116.—Smelting and Distilling Zinc.

On breaking a cake of spelter, a beautiful crystal structure, with a bluish-white colour, will be observed. The metal melts at from 700° to 770°, and, on volatilising, catches fire, burning with a beautiful blue flame in the air, heightened in brilliancy if powdered nitre be thrown over the burning metal. It thus produces a white powder, the only oxide of zinc, which has been proposed as a substitute for white lead, because it is free from the poisonous qualities of that pigment.

Of recent years rolled zinc has come into extensive use for a great variety of purposes, especially in domestic life; and has largely replaced tinned iron and lead in the construction of all kinds of utensils, the lining of cisterns, and covering of roofs. It soon tarnishes by the action of air and moisture; but once arrived in this condition, it remains, under ordinary circumstances, unacted on for years. Hence two highly valuable purposes it is applied to—viz., the lining of water cisterns in place of lead, and the construction of pipes for carrying off water, instead of those of cast-iron, formerly in constant use. With great comparative strength and durability, it combines, in the form of thin sheets, considerable lightness; in this form "going a long way," to use a common saying.

The extensive application of voltaic electricity to electro-metallurgical purposes has largely increased the use of zinc of late years; for, employing an electrical phrase, it is the most "positive," or readily acted on, of any of the ordinary metals. As met with in commerce, it is, however, so impure, even in the state of the best rolled sheet, as to be readily acted on by dilute sulphuric acid, which would cause great waste if so used in voltaic batteries. To obviate this, for such purposes it is first washed over with a little dilute sulphuric acid, and then mercury is rubbed on its surface. An amalgam or union of the zinc and mercury takes place, and thus the zinc is freed, to a considerable extent, from the other metals it may contain, as iron, manganese, &c., and sustains no chemical action until the electrical circuit is closed, when an equivalent portion of zinc is dissolved for an equivalent portion of copper, or other metal, deposited in any electro-metallurgical processes.

Galvanising consists in coating an iron surface with zinc, which is readily effected by dipping a clean iron sheet, nail, &c., into a pan of melted zinc, the surface of which should be kept covered with melted fatty matter, to prevent oxidation. The result is very similar, in some respects, to the coating of iron plate by tin, but has the advantage of much greater durability. It has the disadvantage, however, of frequently rendering the iron brittle; so much so, that we have seen a piece of the latter in rod, three-eighths of an inch square, broken by one bend. The surface of the iron also attains a kind of greasy or soap-like feel, which prevents it taking hold of any surface. For example, some years ago a contract was entered into by the government with a London firm, for the supply of mops, in which the ordinary iron nail was replaced by a "galvanised" one; that is, one covered with zinc. On this being inserted in the mop-stick and trundled, instead of the nail holding in the wood, it flew out, and some hundreds, or perhaps thousands, of mops became indigestible food for the sharks, and other ravenous *feræ* of the "great deep," thus unwittingly supplied to them by the sailors of H.M.'s navy. The rusting of the ordinary iron nail in the wood prevents such an untoward result.

Independent of its metallic uses, zinc is a metal but little employed. Its oxide, as before mentioned, has occasionally been used as a substitute for white lead; but it is deficient in body, and does not follow the brush, or cover well. The sulphate of zinc, or white vitriol, is used in medicine, chiefly in solution, as a cooling application, especially for the eyes, for weakness of which it is almost a specific. The sulphate of zinc, as a bye-product has some uses.

Alloyed with copper, the valuable double metal, brass, results, of which we shall have presently to speak more fully. Frequently, however, in place of employing the metal to mix with copper, calamine is used—a method of producing brass that will be explained hereafter.

The analysis of zinc ores, and the detection of the metal, are easy problems for solution by chemical analysis; for, unlike most other metals, it forms but one oxide, the protoxide; and this is soluble in all the ordinary acids. *Calamine*, the carbonate; *Spartalite*, the oxide; and *Blende*, the sulphide, are all capable of solution in nitric acid, the latter becoming partly oxidised with the formation of sulphuric acid, and the deposition of sulphur—a similar result to that we described as taking place in the analysis of galena, at p. 115, *ante*. When in neutral solutions—that is, those free of acid—sulphuretted hydrogen precipitates it as a white hydrated sulphide; and the same occurs by substituting the hydrosulphate of ammonia, the precipitate being re-dissolved by the addition of either hydrochloric or nitric acid in excess. The caustic and carbonated alkalies precipitate a white hydrated oxide, which is re-dissolved only by ammonia in excess, but not by the other alkalies. By the blowpipe, the oxide, resting on a charcoal support, and moistened with a solution of

nitrate of cobalt, produces a green mass, effected by the oxidating flame. Oxide of zinc is distinguished from other white oxides by turning yellow when heated, but regaining its white colour on cooling.

For quantitative analytical purposes, zinc may be precipitated as the carbonate from solutions free from ammonia, or ammoniacal salts. On being ignited in a crucible, the carbonate is converted into an oxide, every forty grains of which, in round numbers, may be estimated as containing thirty-two of zinc. According to the usually-received equivalent of zinc, however, it should be stated, that when 40·6 or 40·75 grains of the oxide are present, 32·6, or 32·75 grains of zinc are in the oxide. If separated as a sulphide from neutral solutions, by hydrosulphate of ammonia, it should be dissolved by hydrochloric acid, and precipitated by carbonate of soda, after heating, to drive off all free sulphuretted hydrogen (hydrosulphuric acid): it is then reduced to an oxide, and weighed as above. Generally speaking, there is little difficulty in separating zinc from the earths, as they are not precipitable by hydrosulphuric acid or hydrosulphate of ammonia, whilst zinc is. Baryta and zinc are readily separated, owing to the earth affording an insoluble precipitate of the sulphate; whilst the zinc sulphate is retained in solution. Alumina and oxide of zinc, precipitated together, are separated by excess of caustic potass, in which the alumina alone is soluble. When alumina or magnesia, together or separately, are present with zinc, it is best to convert the oxides into acetates, and to precipitate the zinc by hydrosulphuric acid, which it is capable of doing when the metal is in solution with organic acids. The sulphide of zinc can then be converted into oxide by solution in hydrochloric acid, precipitation by carbonate of soda, and subsequent ignition. The general details of the routine of qualitative and quantitative analysis, have been given when we pointed out the method of analysing iron ores at p. 55, *ante*.

The preceding pages have afforded sufficient information in respect to mining, ores, smelting, and other operations, to enable our readers to understand all the important points involved in each of those matters. Improvements, modifications, &c., of these will subsequently come under our notice, in a manner similar to that adopted in our treatment of the metallurgy of iron and steel.

We shall now proceed to detail the various alloys of copper, tin, lead, and zinc; and describe, as far as the limits of this work will permit, the chief points of importance that must be carefully attended to for ensuring success, mentioning also some of the leading applications to which the metals and their alloys are put in various branches of manufactures, art, domestic purposes, &c., &c.

The Alloys of Copper, Tin, Lead, and Zinc.

One of the most difficult questions of solution, so far as chemical science is concerned, is that in relation to alloys; the point to determine being, whether the metals best unite in such proportions as are indicated by what chemists term "equivalent proportions." While we know that oxygen always unites in the proportion of 8, and its multiples, with any other body, hydrogen being taken as the standard, or unity; that 28 parts of calcium combine with 16 of oxygen and 6 of carbon to form the definite compound commonly recognised as chalk or carbonate of lime, 50 parts of this substance being so produced; that, in round numbers, 32 parts of zinc, and 8 of oxygen, afford 40 parts of the oxide of zinc; that 28 parts of iron unite with 8 of oxygen, to form 36 parts of the protoxide of iron; that the black or protoxide of copper is composed of nearly 32 parts of the metal and 8 of oxygen;—despite all this definite and undoubted knowledge, instances of which might be multiplied to some thousands, yet we are still uncertain that copper is best alloyed with zinc, tin, or any other metal, in those proportions, or even their multiples, suggested by chemical law, universally true in every case, except that regarding alloys.

It must not be supposed, however, that we are suggesting the impossibility, still less the fact, of such proportions, or their mutiples, ruling the results of alloys. The preceding remarks are intended simply to suggest the great difficulty that at present surrounds the subject. Nothing in the whole range of chemistry is worse defined than the law of metal-combination, *inter se;* and we can point out no reliable experiments, or rather the conclusions than can be drawn from such, on which to found a well-defined, generally applicable, and, still less, an accurate theory.

Numerous circumstances conspire to influence the combination of metals. Taking first the question of specific gravity—that alone is sufficient to account for great irregularity of result. We have already pointed out a peculiarity in this respect relating to iron and silver, in which it was seen that the latter metal interlaced itself rather than united with the iron. Some experiments in the attempted union of platinum and iron were recounted as affording anomalous results, But other singular physical results arise in the union of metals as alloys. As a rule, the alloys are always more fusible than one or more of the individual constituents. For example, an alloy of three parts of cadmium, four of tin, eight of lead, and fifteen of bismuth, may be made fluid at a temperature below that of boiling water, 212°. But still more astonishing is it that three parts of tin, five of lead, and eight of bismuth, will become fluid at 210°, although the lowest temperature of fluidity of any one must be considered as, in either case, not less than 440°. It is, therefore, extremely difficult to derive any information from such sources, as to the changes that occur, and their causes, in the union or mixture of one or more metals, whether as regards their chemical or physical affections.

But the questions of specific gravity and fusibility, or the relations of the law of gravitation and those of heat, do not alone present points of

difficulty in respect to the results of alloying metals. Their tenacity, and, consequently, their hardness, malleability, ductility, &c., are all affected; added to which, as we might reasonably expect, their colour also undergoes various changes. Frequently the smallest change in the proportion of metals respectively in alloys is of the utmost consequence. Thus certain kinds of speculum metal—that is, an alloy of copper and tin with arsenic—are exceedingly brittle; quite devoid of malleability; so exceedingly hard as to be utterly beyond the pale of the softness characterising each of the constituents, and, indeed, resisting a steel file, although each of the metals composing it is capable of being cut by an ordinary knife with perfect ease. Similarly, arsenic added to lead causes the hardness of ordinary shot, used for sporting purposes. In respect to colour, we may instance the case of an alloy of copper with aluminium, which resembles gold so closely as to have obtained the name of Abyssinian gold, and which is now largely used in the manufacture of cheap jewellery, watches, &c.

An alloy may be highly elastic, whilst its constituents are all but devoid of that quality. One of the best tests of permanent elasticity is that of producing musical notes; and, in this point of view, lead holds, amongst all metals, the lowest position; so much so, indeed, that it is an excellent foundation for astronomical instruments, in preventing their vibration. Sound is the result of vibrations in all bodies, but especially those of a solid nature. Now, neither copper nor tin is especially noted for sonorousness; and, therefore, under ordinary circumstances, cannot be reckoned as remarkably elastic. Common experience teaches this. Yet an alloy of copper and tin forms one of our best materials for making bells, gongs, and other musical sound-producing arrangements.

The "temper" of an alloy—an almost indefinable term, taken apart from its application to steel, not in its cause, but in its results—is another important qualifying point in relation to alloys; but this we shall more fully define presently. It will be sufficient here to state that, by using a certain mixture called temper, the combination of two or more metals, whilst fused, is greatly assisted. In the manufacture of pewter, for example, a temper, composed of tin and copper, is added, for the purpose of introducing an exceedingly small portion of copper.

The chemical examination of an alloy does not generally present any great difficulty. It is remarkable, however, how much the chemical affinities of metallic bodies are modified by being alloyed, instances of which we shall have to notice, when dealing with various metals, in our future pages. This fact would seem to indicate that an alloy, when properly and perfectly effected, must, more or less, partake of a chemical union in its nature, and not a mere admixture of metals; for if the latter alone took place, the natural affinities of each would neither be masked nor suspended. There is little doubt but that the perfect character of an alloy much depends on the fusing-points of each metal being closely approximate. Thus tin and lead; tin, cadmium, bismuth, and lead; and other metals similarly circumstanced in respect to their fusing-points at low temperatures; iron and manganese, as already illustrated in the manufacture of spiegeleisen, and in the Bessemer process, &c., &c.—all form definite alloys, in which the chemical, physical, and other qualities are completely lost to all appearance, so far as each individual element is concerned. On the other hand, we have seen, when describing certain alloys of iron and steel—especially with silver—that such intimate union does not take place; on the contrary, the silver in one experiment could even be detected by the eye, after fusion, and by the dissecting action of an acid, which will act on iron, but not on silver.

We have already noticed that certain anomalies are presented in respect to the specific gravity of alloys, and the individual specific gravity of their constituents: and these anomalies must arise from the fact that a condensation of the two into a less bulk frequently occurs, denoting chemical action between them. We have related a singular instance of this, that occurred in certain experiments undertaken by Faraday; and we repeat the quotation already given from his able paper. "Equal parts, by weight, of platinum and steel form a beautiful alloy, which takes a fine polish. * * * * The specific gravity of this compound is 9·862." Now, if the specific gravity of an alloy was always an arithmetical mean between that of its constituents, then as, in round numbers, that of steel is 8, and that of platinum 21, we should have, as the specific gravity of the alloy, the result of $\frac{8 + 21}{2}$, that would give 14·5, which is much above the value actually obtained." Hence, in this case, an amount of expansion of the particles of the alloy must have resulted. Certain illustrations of this may be drawn from various departments of chemistry. Thus, if ammonia gas and hydrochloric acid gas be allowed to commingle, they form a solid, ordinary sal-ammoniac, that is several hundred times more dense; or, in other words, has about 1,000 times the specific gravity of its separate constituents. Again, if equal measures of strong sulphuric acid and water be mixed together, the two occupy considerably less space *together* than the sum of their bulks separately. In both these cases, therefore, we perceive that a *condensation* occurs, due to chemical action. Instances of an opposite kind occur; but we have given sufficient to illustrate the principle on which the variation of the specific gravity of an alloy, from the mean of its constituent metals, can be accounted for. The object is one of considerable difficulty, and will require much more extended investigation than has yet been made for its complete elucidation.

We must now turn to the practical part of our subject.

Certain precautions must be observed in reference to the treatment of metals intended to

form alloys, dependent not only on their chemical, but physical character. Thus zinc, added to melted copper to form brass, is greatly liable, not only to oxidation (which would materially interfere with the quality of the alloy), but also to great waste, owing to its ready volatility. This was early discovered. We have already stated that 150 years ago, zinc was at an enormous price, compared to its present one. To avoid the loss consequent on the causes just mentioned, so early as the year 1781, a patent was taken out, an extract from the specification of which, will show that the difficulties we have alluded to were not only understood, but it was attempted to obviate them as far as possible. Emerson, the patentee, says—"I take spelter ingots and melt them down in an iron boiler; I then run the melted spelter through a ladle with holes in it, fixed over a tub of cold water (the modern method of granulating metals), by which means the spelter is granulated, or 'sholed,' and is then fit for making brass on my plan. I then mix about fifty-four pounds of copper shot (that is, the granulated metal), about ten pounds of calcined calamine [the carbonate of the metal, already described], ground fine, and about one bushel of ground charcoal together; I then put into a casting-pot a handful of the mixture, and upon it I put about three pounds of scholed (granulated) spelter; I then fill up the pot with the said mixture of copper shot, calcined calamine, and ground charcoal. In the same manner I fill eight other pots, so that fifty-four pounds of copper shot, twenty-seven pounds of sholed spelter, about ten pounds of calcined calamine, and about one bushel of ground charcoal, make a charge for one furnace, containing nine pots for making brass on my plan. My chief reason for using the small quantity of calamine in the process, is more for confining the spelter by its weight, than for any increase arising from it; and I have frequently omitted the calamine in the process. The pots being so filled, are respectively put into the furnace, and about ten hours complete the process; and from this charge I have, on the average, eighty-two pounds of pure fine brass, fit for making ingots, or casting plates for making brass battery ware, or brass latten; and my brass, made as aforesaid, is of a superior quality to any brass made from copper and calamine."

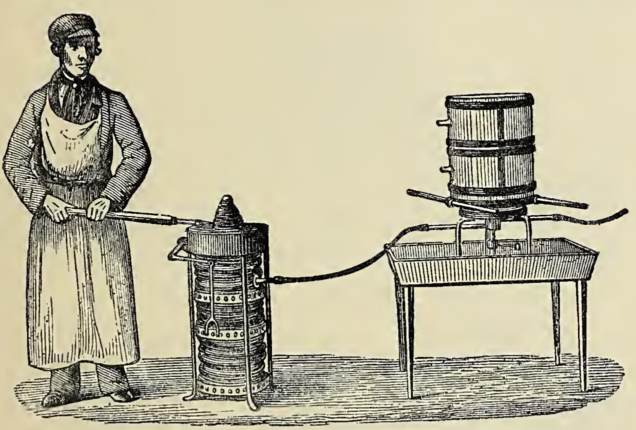


Fig. 117.

Whatever success Mr. Emerson conceived himself to have obtained, or progressive advance by his method beyond that arrived at through others then known, he certainly seems to have had considerable doubt as to the principles involved in the process he patented. Perhaps the low state of chemical knowledge of the day, and a lingering leaning to alchemical traditions, made his plan incomplete, tedious, and uncertain. We merely quote from his patent to show, that, at an early period of our metal manufacture, so far as the alloys of copper are concerned, several difficulties that were met with were, nevertheless, combated.

In producing alloys on the large scale, the metallurgist has of course at his command, furnaces, crucibles, &c., suitable for each speciality of his processes. But many of our readers may desire to experiment on making alloys on the small scale; in fact, by such means all the inventions that have resulted in the iron and steel production have arisen. It is self-evident that the limited apparatus of the laboratory must in all cases be employed to guide to successful trials on the large scale in the manufactory.

A wind-furnace is generally necessary for such experiments, because with the exception of lead, and some metals of minor importance, as antimony, &c., it requires a high temperature for their fusion. Wind-furnaces and others for similar purposes may be purchased of the leading philosophical apparatus makers in this country, on the continent, &c. They occupy comparatively little space, can be moved from place to place, and merely require that the outlet for the results of combustion should be connected with a flue or chimney of moderate height. Crucibles of all kinds are readily obtained at the metal-warehouses in all our large towns. Of course their choice must depend on the object to which they are to be applied.

A very ingenious arrangement has been produced by Mr. Griffin, of Garrick-street, London, which has come largely into use for chemical purposes, and is also employed by metallurgists in cases wherein an intense heat is frequently required. The principles of its construction are similar to those of the gas furnaces ordinarily used for boiling, evaporating, &c., in the laboratory—namely, the combustion of coal gas and common air together. Indeed, this method is now in common use in our houses for many

domestic purposes; but as it can afford a temperature sufficient to melt cast iron, and to soften almost to the fusing-point, both wrought iron and platina, we shall introduce a description of its arrangement.

Our illustration (Fig. 117), will give an idea of this arrangement when in use. On the right

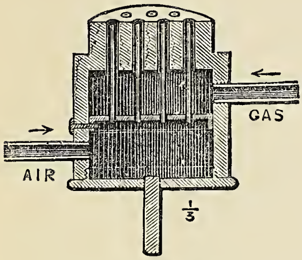


Fig. 118.

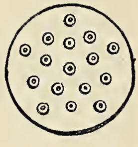


Fig. 119.

is the gas-furnace placed on a table; in the centre we have the bellows which supply the air-blast, driven by a man, who at the same time can superintend the entire operation.

is applied from beneath. The following engravings illustrate the plans by which the heat is applied from above.

Gas Furnace heated at the top, exhibited in Section by Fig. 120—*a* is the gas-burner; *b* is the support for it, when used below the furnace; *c* is the iron tripod support for the furnace; *d d* are two perforated clay plates, adapted to the gas-burner, *a*; *e e* are two clay cylinders.

The interior of the furnace, as represented by Fig. 120 is built up as follows:—The clay plate, *d*, is put upon the tripod, *c*. Over the central hole in *d*, the clay cylinder (Fig. 121) is placed, and upon that cylinder two or three of the clay plates represented by Fig. 122. Upon these a porcelain or platina crucible is placed. If it be of platina, a piece of platina foil may be put between the crucible and the uppermost clay plate, to protect the crucible from contact with particles of iron, or against fusion with the clay. The crucible is to be covered by the plumbago jacket, Fig. 123. The space between this pile in the centre of the furnace and the two cylinders, *e e*, which form the walls of the furnace, is to be filled with flint stones, or gravel, washed clean and dried. The stones which answer best are rounded, water-worn pebbles, of half an inch to one inch diameter. These may be piled up to

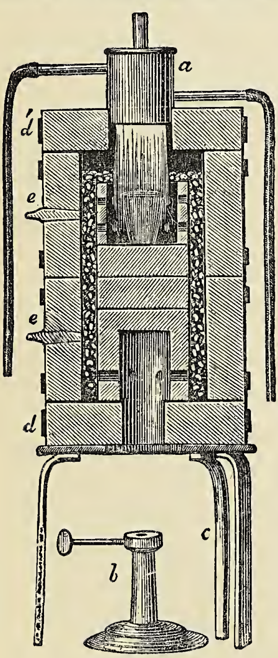


Fig. 120.

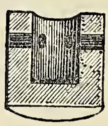


Fig. 121.

Fig. 122.

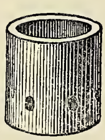


Fig 123.

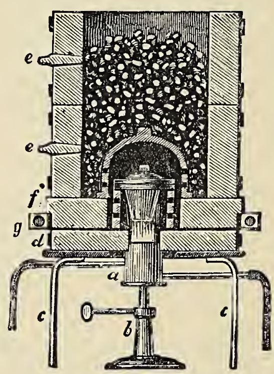


Fig. 124.

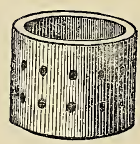


Fig. 125.

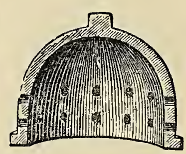


Fig. 126.

Fig. 127.

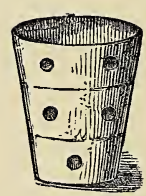


Fig. 128.—Faraday's Furnace.

Fig. 118 is that portion through which the air and gas pass together. Fig. 119 shows the holes at the top of Fig. 118, which only represents them in section. These, in fact, form the heating portion of the furnace.

Mr. Griffin has adopted two different methods of applying heat. In some cases, he prefers to drive the heat downwards; in others, the heat

the top edge of the jacket, Fig. 120. The number of clay plates must be such as to bring the top of the crucible to the distance of two inches, or two-and-a-half inches at the utmost, from the the flat face of the gas-burner, *a*. In some cases, merely one of the furnace cylinders, *e*, is necessary; in which case the crucible and its jacket is placed directly upon the cylinder,

Fig. 120 ; and when only a moderate heat is required, even the packing with pebbles may be dispensed with. Another means of diminishing the heat is that of increasing the distance between the gas-burner and the crucible.

Fig. 129.—Bronze Strainer, from Pompeii.

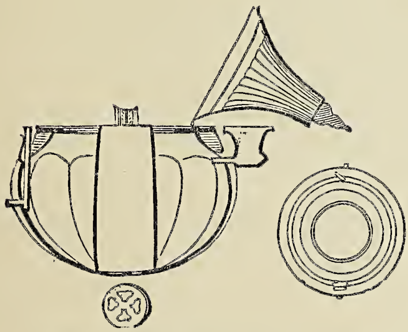


Fig. 130.—Metal Urn, from Pompeii.

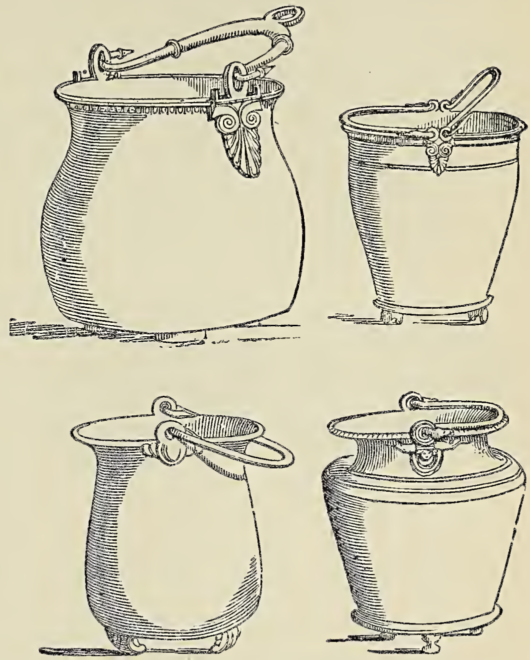


Fig. 133.—Bronze Vessels, from Pompeii.

In Fig. 120, it will be seen that the gas-flame is driven, by means of the blast, directly on to the crucible. Another illustration represents that form of the furnace in which the heat is produced beneath the crucible. (See Fig. 124).

The packing of this variety of furnace is performed as follows :—The clay plate, *d*, is placed upon the tripod-stand. The crucible jacket, Fig. 125, or one similar, but of larger size, is placed upon the plate, *d*. The crucible and its cover is then put into its place, and is covered with the dome, Fig. 126, which must rest upon the lifter, *f*, and must be of such a width as to clear the crucible easily when lifted. The internal height of the dome should be such as just to clear the top of the crucible cover. Consequently, where crucibles of different sizes are used, domes of different sizes are also necessary. Observe, distinctly, that the crucible and its support are to rest upon the plate, *d*, and the dome upon the lifter, *f*. The furnace cylinders, *e e*, are now to be superposed, and the spaces between the dome and the cylinders, and that above the dome, are to be filled with small pebbles, as already directed. The gas may then be lighted ; the blast of air set on ; and the operation be allowed to proceed.

Fig. 127 represents a plumbago crucible, which is used to suspend the inner crucible over the gas-flame. By means of such a furnace, six inches in diameter, three pounds of copper or cast iron can be fused in a quarter of an hour. From eight to ten pounds of copper or cast iron can be melted in an hour's time ; and thus a portable and almost instantaneous source of intense heat is afforded. We have seen fused masses of

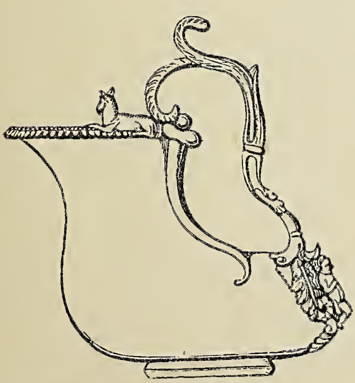


Fig. 131.—Bronze Vessel, from Pompeii.

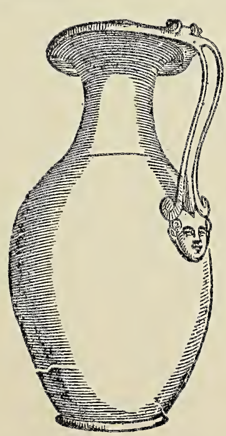


Fig. 132.—Bronze Vase. from Pompeii.

these metals thus produced, and, indeed, the heat afforded is so great that neither Hessian nor English crucibles can withstand it, both being completely vitrified during a lengthened operation.

We may here notice, that whilst, at the present day, we may command any amount of heat by proper construction of either wind or blast furnaces, it has, until recently, been difficult to get melting-pots or crucibles for fusing gold, copper, silver, or their alloys, that could long withstand the action of heat, and of the metals on the surface. All pots or crucibles containing silicious matter are soon acted on, the silicic acid acting as a kind of flux, or the metal operating in that manner, by which the destruction of the crucible is eventually effected, mostly in a

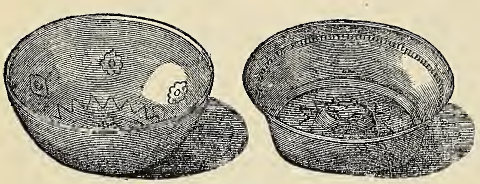


Fig. 134.—Egyptian Brass Vessels.

short space of time. The interior of the furnace always requires constant renewal, which is done by lining it with Stourbridge, Dinas or some other clay of a refractory nature. The Dinas brick has long been in high favour for this purpose. It has been found that the scrapings of a macadamised road, or ganister, used as a lining of the Bessemer converter, is extremely valuable, from its refractory character and cheapness; and it has consequently been largely used.

Among the best kinds of crucibles now offered for metallurgical use, are those manufactured under Morgan's patent, and sold as the plumbago crucible. They received the prize medal in 1862, at the London Exhibition; and have had similar success at Dublin, and some foreign exhibitions. They have stood the test of use in the English, French, colonial, and several other mints, and have been mostly adopted in large metallurgical establishments, both at home and abroad. It is considered that their quality is uniform, and they withstand the greatest heat without danger of fracture. Their average durability for gold, silver, copper, and other ordinary metals, is from forty to fifty pourings; and, in some cases, as many as one hundred have been reached. It is stated that they never crack; while they heat more rapidly than most other kinds. They only require one annealing; that is, a gradual exposure to heat, and subsequent slow cooling; and after having been so annealed, they may be taken hot from the furnace, and even be dipped in cold water without risk of fracture. In steel-melting they are said to have saved a ton and a-half of fuel to every ton of steel that has been melted; and when used for melting zinc, they last much longer than iron pots hitherto most generally employed; there is also the additional advantage that, with them, no loss can occur through the union of the melted zinc with the iron of the pot—an occurrence of constant possibility when iron melting-pots are employed. When used to melt malleable cast-iron they average an amount of work equal to double that of an ordinary English crucible for a period of seven days. There are many other forms of highly refractory crucibles now in use.

Those conversant with ordinary laboratory operations, will be well aware of the importance of having thoroughly resisting linings to the furnace; and still more so, of possessing crucibles that may be depended on. We speak feelingly in remarking, that after having kept a pet Berlin porcelain crucible, for analytical purposes, in all but constant use for three years, our hopes and crucible were simultaneously dashed to pieces by the careless swinging of the coat-tails of a "friend." But, in practical metallurgy, when important consequences may arise, a really good crucible is as invaluable as it is absolutely necessary.

As already intimated, the size of both furnaces and crucibles, or melting-pots, and their number, must, of course, depend on the extent of operations carried on in any works. And as these are questions of purely mechanical detail, we must omit their further consideration; having said sufficient in respect to the general principles that are followed, whether in large or small establishments.

For experiments on alloys of metals, whose fusing points do not exceed those of zinc and lead, a very simple furnace, suggested by Dr. Faraday, answers admirably, and having constantly employed it, we recommend its use to our readers. It is made by boring holes, an inch in diameter, at equal distances, through the outside of a blue pot, such as is used by refiners. The holes are easily made, and should be neatly finished off. An iron grid is dropped in so as to rest two inches above the lower series of holes, and the fuel may be small pieces of coke or charcoal. The furnace should be bound round by iron wire, so as to prevent it falling to pieces on being heated. One of these will last for a long time, and is useful for a variety of purposes. Its cost is very slight, being not more than a couple of shillings altogether. The engraving on page 124, Fig. 128, represents one of these simple contrivances.

With these preliminary remarks on the apparatus, &c., required generally for producing alloys, we proceed to explain more definitely their nature, preparation, uses, &c.

Brass.—This alloy of copper, according to historical statement, is one of the earliest kinds of metal alloy used. But it must not be supposed that the "brass" mentioned in sacred and profane writings, was the brass of our day. Copper, and copper alloyed with tin, were similarly called; and, most likely, the brass of Scripture relation was often copper. As to the history of brass, the late Mr. Barlow makes the following remarks:—

"This compound metal was known to the

Ancients, as we find by many parts of the Old Testament, as well as from various ancient historians; but it does not appear that they were properly acquainted with its nature or composition. They considered it as a particular kind of copper, found native in the mines in which zinc and copper seem to have been found in the proper proportion for its production. It was denominated by the Greeks *Orichalcum;* that is, *Æs montanum*, a particular sort. *Æs Corinthiacum* is generally supposed to have been a mixture of gold, silver, and copper, metals with which Corinth abounded, melted down together at the burning of this city by the Romans, A.C. 496. At what time the actual constitution of brass became known, is not stated with any certainty; but it appears unquestionable, that in early times it was exceedingly valuable, from the supposition of its being a rare and distinct metal, or particular species of copper; it being stated that, as the mine in which it was obtained failed, it was supposed to be impossible to obtain it in any other way, and that in value it held a middle place between gold and silver." A remarkable instance, we may add, if the preceding account may be completely relied on, of the bliss of ignorance; for, after all, polished brass is just as good as gold for a great variety of purposes; but it has not the "name" at this day of its great plenty.

After so many centuries that must have elapsed since the working of brass and other alloys of copper became known, it is interesting to find that the early followers of the art were led to many contrivances, for domestic and other uses, parallels to which we find at the present day. As works of art some of them were of great beauty. One of the most beautifully symmetrical vases that we have yet seen, although it was perfectly plain, and simply depended on the beauty of its unadorned shape, was copied by an eminent porcelain manufacturer near Glasgow, from an original obtained from Pompeii; and its admirable contour charmed every one who had the pleasure of inspecting it. Indeed, we fancy that correct ideas of art in metal-working were as much possessed in advance of us by the ancients, as our knowledge of the production of the material now exceeds theirs. If they did not know how to make brass, at least the ancients knew how to apply it to ornamental and useful purposes. Amongst the smaller kind of vessels so produced, there is a beautiful specimen of a bronze strainer, found at Pompeii and illustrated in Fig. 129. Figs. 130, 131, 132, and 133 illustrate various domestic vessels in bronze found in the ruins of Pompeii, and Fig. 134 a pair of Egyptian brass vessels.

The art of making brass from a union of copper and zinc, has not been followed in England for more than two centuries. It was long confined to Germany, where the process was strictly kept secret. The earliest account of brass-making in England, dates at about 1649, when a work was established at Esher in Surrey; but it failed from want of support. But in those days this country was dependent on foreign countries for both copper and zinc; and as the cost of transit was as enormous as it was irregular, it was, of course, impossible that such works could succeed. Indeed, so late as 1731, we have already stated that zinc, in the metallic state, cost many times as much as it does at the present day. But, independently of this, at a much later date we have noticed, by a quotation at p. 123, *ante*, that the process of brass-making was a most tedious and uncertain affair, even so recently as 1781.

Forty years ago the manufacture of brass was by no means in an advanced condition; for, like all the arts or manufactures dependent on chemical or other branches of science, progress must depend, to a large extent, on the aid of experiment and sound scientific induction. The following somewhat quaint description illustrates the usual method of producing brass in many parts of England at that period:—It is customary to calcine all sorts of calamine [the carbonate of zinc described at p. 119 *ante*] before they are employed for the making of brass. In some places the ore (purified and picked English calamine) is piled in conical heaps of twelve feet in diameter, and six feet high, with layers of fuel intermixed. Such a pile burns about twenty-four hours. In other places the calcining is effected in a furnace built for the purpose, in which the ore is excluded from immediate contact with the fuel. In England, the calcining furnace resembles a baker's oven, with an apartment at one side for the fuel, wood, or pit coal; the partition betwixt the two chambers is open at the top for suffering the flame to pass over and reverberate on the mineral. The capacity of the furnace is such as to receive a ton of calamine spread four or five inches thick. The process lasts four, five or six hours; the ore being constantly stirred and turned with long iron rakes. * * * * The calcined (roasted) calamine is next reduced to powder by iron mallets, or mills. * * * * The zinc contained in calamine is in a state of calx, and requires to be revived [reduced, we presume] by the mixture of inflammable substances, in order to its uniting with copper. The inflammable matter generally made use of is charcoal. The harder sorts of charcoal are said to answer better for this use than the soft, occasioning the yield of zinc to be greater. The quantity of charcoal is usually equal to that of the calamine; but Cramer observes, that though an equal weight is necessary in small essays, in the larger works an equal measure is sufficient; the quantity of charcoal, on this supposition, is from one-sixth, or a little less, to somewhat more than one-fourth of the calamine, according to their gravities."

We must here break the thread of our quotation by remarking on the loose manner pursued so recently in measuring quantities, as illustrated in the immediately preceding instructions given in respect to the charcoal required for reducing the zinc. But that was, to a great extent, characteristic of pure and applied chemistry even so recently as 1820—'25, the period to which we are now referring, and when the doctrine of

chemical equivalents was but barely understood, and still less acted on.

"It is supposed necessary that the calamine and charcoal be reduced into very fine powder, especially the former, that they may be well mixed together. In some places the mixture is performed by means of rakes drawn several times backwards and forwards through the powders, which are moistened with a little water or urine; in others they are circumagitated together. At Goslar a little alum and common salt are added, which are said to give the brass a better colour in the first fire." It will be noticed that scarcely a word has been said, in the previous remarks, about zinc as an ordinary metal. Indeed, fifty years ago it was so scarce, that in an edition of *Elements of Chemistry*, which was published in 1829, the author gravely advises his readers that possibly they may meet with the metal zinc at some of the brass-founders; little imagining that, in a few years afterwards, it would become far more common and universally used than almost any other metal except iron. The writer that we have quoted goes on to give some account of the method of purifying copper, that we have previously explained. He then continues:—

"The proportion of this calcined ore (calamine) and copper for forming brass, varies in different works, from 40 to 61 of zinc and copper respectively. The two combined (mixed) in these proportions, are placed in crucibles made of Stourbridge clay, mixed with an equal quantity of the same clay calcined, or old pots powdered. Their capacity is such as to receive, from five to twelve pounds of copper, with the requisite proportion of the calamine; and a furnace will receive several such crucibles. The fire is at first gentle, and increased by degrees till the metal comes into fusion, in which state it is kept for some time, that the copper and zinc may be more perfectly united. To promote this effect, the crucibles are, in some places, occasionally shaken. The fire is continued from nine to sixteen hours; in most places eleven or twelve. * * * The fuel is applied twice, the first quantity being consumed in nine hours; the other in five hours. In some works, if not all, when the crucibles are put in the furnace, the spaces between them are filled with damp fern, cut into cakes, like hay from a rick, with which the crucibles likewise are covered. Above this are put two bushels of coal, and the furnace is covered with an iron plate—a little way at first, and, when the heat is strong, the whole way: a small quantity of coal is occasionally added, and the clinkers removed. The appearance of yellow fumes is a sign that the process is completed. After sufficient fusion, the metal is lifted, with the crucible, by a pair of tongs formed for the purpose, and the brass in each is poured into one large crucible, placed in the furnace to receive it: here it is carefully skimmed, and afterwards cast into flat plates in moulds. * * * The plates of brass, as first taken out of the mould, are brittle; and, in order to render them malleable, they must be annealed for some hours in an annealing furnace; the brass is then fit for the market."

It would be very interesting to many, and amusing to some of our readers, to trace the gradations of improvement that invariably may be noticed in the applications of science to the art and manufactures. This, however, would be simply impossible of attainment; because any person who would attempt it with a hope of success, must have qualifications of intellect and experience that would disincline him for the research: in other words, he would overrun the "Rubicons" that his more ignorant, but not less persevering, fellow-men have had to pass. Yet it is refreshing, at times, to scan over the bombastic pretensions which those who, in former years, considered themselves as masters of any subject in science, exhibited. They assigned to ethereal, and other mythical agencies, the production of results which, in our more practical day, we ascribe to dry, common-place cause and effect. Fancies empirically governed common sense, which, after all, is simply the beginning and end of science. Separate all our modern science—which, by the way, is far from being free of hypotheses that must necessarily, in the end, prove false—from the Baconian system of experiment first, followed by sound induction, and we should at once plunge into a kind of chaotic error, that would restore to us the darkness of the middle ages, and bury in oblivion all the labour of the honest sons of philosophy.

After this short digression, permissive, perhaps, from the peculiar scientific eccentricities developed in the quotations we have made, we return to the practical part of the subject.

As the production of zinc, in the metallic form, became better understood, so the method of producing brass improved. At the same time, as we shall subsequently notice, some portion of the old processes, especially that of cementation, is yet retained. It is, as we shall hereafter show, analogous to the "case-hardening" of iron, or its external conversion into steel.

The difficulty which occurs in making a homogeneous alloy of copper and zinc, arises from the different points of fusion of each. That of zinc is pretty well ascertained as being not very much beyond the fusion-point of lead. But in respect to copper we are not so certain. Whilst zinc melts below a red heat, it is required that a temperature, at least producing what is usually called a yellow, and verging on a white heat, should be employed to melt copper.

Now, it follows, that if we put zinc into melted copper, the temperature of the latter is so high as to cause the volatilisation of a portion of the zinc. The mere loss of the zinc is not the only point of importance, because the ratio of its price to that of copper is, on an average, nearly one to four or five; copper averaging about ninepence, whilst spelter usually fetches twopence per pound. Here we do not speak of the retail prices, but of those that obtain in commercial circles for the largest purchases.

But another result arises from this circumstance. If a portion of the zinc is volatilised, then, presuming that all the best or most perfect alloys should have a definite composition,

chemical or otherwise, the results of a fusion or admixture in the crucible would vitiate or set aside the law of definite combination. Hence it has been desirable to fix the limits between which the loss of zinc and its remaining quantity in the crucible, as added to melted copper, affect the ultimate result. The following account of experiments made by Mr. Holtzapfel cannot be perused without interest by our practical readers, especially as he is so well known for his varied and valuable communications to the facts and literature of mechanical science, whether as regards wood or metal. In his *Turning and Mechanical Manipulation*, and the first volume of the second edition of the work, he observes, relating the result of experiments made to determine the various difficulties that we have suggested or explained :—

"The zinc was added to the melted copper in various ways—namely, in solid lumps, in thin sheets hammered into balls, poured in when melted in an iron ladle ; and all these, both whilst the crucible was in the fire, and after its removal from the same. The surface of the copper was, in some cases, covered with glass or charcoal, and in others uncovered ; but all to no purpose, as from one-eighth to one-half of the zinc was consumed with most vexatious brilliancy, according to the modes of treatment [see, in respect to this, an account of analogous experiments intended to remove phosphorus from iron in the Bessemer process, at p. 91, *ante*] ; and these methods were therefore abandoned as hopeless. I was the more diverted from the above attempts by the well-known fact, that the greatest loss always occurs in the first mixing of the two metals, and which the founder is in general anxious to avoid : thus, when a very small quantity of zinc is required, as for the so-called copper castings, about four ounces of brass are added to every two or three pounds of copper ; and, in ordinary work, a pot of brass weighing 40 lbs., is made up of 10, 20, or 30 lbs. of old brass, and the remainder of copper. These are first melted a short time before pouring ; one-third of the new metals or the zinc is plunged in, when the temperature of the mass is such that it just avoids sticking to the iron rod with which it is stirred. In mixing the copper and zinc for my experiments on brass, an entirely different course was therefore determined upon—namely, to melt the metals on a much larger scale, and in the usual proportion ; that is, 24 lbs. of copper to 12 lbs. of zinc (in order) to learn the first loss of zinc when conducted with ordinary care ; then to re-melt a quantity of the alloy over and over again, taking a trial-bar every time, in order to ascertain the average loss of zinc in every fusion. From the residue of the original mixture, to make the alloys containing less zinc, by a proportional addition of copper ; and those alloys containing more zinc, by a similar addition of zinc ; and, lastly, to have the whole of the bars assayed, to determine the absolute proportions of copper and zinc contained in all ; and from these analyses to select my series of experiments, as nearly in agreement as I could with the proportions in common use ;—this method answered every expectation.

"Twenty-four pounds of copper, namely, clean ship's bolts—were first melted alone, to ascertain the loss sustained by passing through the fire (*i.e.*, melting these), which was found to be barely a quarter of an ounce on the whole. A similar weight of the same copper was weighed out, and also twelve pounds of the best Hamburg zinc in cakes, about three-quarters of an inch thick, which were broken into pieces.

"The copper was first melted ; and when the whole was nearly run down, the coke was removed to expose the top of the pot, which was watched until the boiling of the copper (arising, probably, from the escape of bubbles of air, locked up at the lower part of the semi-fluid mass) ceased, and the copper assumed a bright-red, but sluggish appearance ; the zinc was then added. Precaution is necessary in introducing the first quantity of zinc, not to set (solidify) copper, which is liable to occur if a large quantity of cold metal is thrown in, simply from the abstraction of heat ; and it is also necessary to warm the zinc, that it may be perfectly dry, as the least moisture would drive the metal out of the pot with dangerous violence. A small lump of the zinc, therefore, was taken in the tongs, held beside the pot for a few moments, and then put in with the tongs, with an action between a stir and a plunge, regardless of the flame, and of the low crackling noise, just as if butter had been thrown in ; the zinc was absorbed, and the surface of the pot was clear from its fumes immediately. The remainder of the zinc was then directly added, in about eight pieces, one at a time, much in the same manner ; but the danger of setting the copper nearly ceases when a small quantity of the spelter is introduced. After every addition, the pot was free from flame in a few moments ; a handful of broken glass was then thrown in, the tile replaced, and the whole allowed to stand for about fifteen minutes, to raise the metal to the proper heat for pouring, which is denoted by the commencement of the blue fumes of zinc.

"The pot was then taken from the fire, well stirred for one minute, and poured. The weight of the brass yielded was 34 lbs. $12\frac{1}{2}$ oz., showing a loss of one pound and $3\frac{1}{2}$ oz., or one-tenth of the zinc, or the $\frac{1}{30}$th part of the whole quantity. The experiment was repeated, and the loss was 1 lb. 3 oz., the difference being only half an ounce. By analysis, the mean of the two brasses was $31\frac{1}{4}$ per cent. ; or, instead of being 8 ounces to the pound, it was only $7\frac{1}{4}$ ounces.

"Twelve pounds of each of these experimental mixtures were re-melted several times; a bar weighing about one pound and a-half being taken each time. The two series of trials were conducted in different foundries, by different men, and quite in the ordinary course of work ; but the loss per cent. of zinc was, in the six experiments, alike in each series ; that is, each bar, after the sixth melting, contained $22\frac{1}{2}$ per cent., or $4\frac{5}{8}$ ounces to the pound of copper. The second fusion in each case sustained the greatest

loss (say nearly twofold); and in the others—taking all accidental circumstances into account—the loss might be pronounced nearly alike in each fusion.

"In making alloys with more zinc, the calculated weight of the first alloys was melted, and the amount of zinc was warmed, and plunged in with the tongs, whilst the pot was in the fire; the whole was stirred and quickly poured: the losses in weight were rather large; but this is common when the zinc is in great quantity. To make the alloys containing less zinc than the alloy (previously named), the calculated weight of copper was first made red-hot, and the respective portion of the brass alloy was then put in the pot, by which means the two ran down together; it being found that the copper, if entirely melted before the brass was added, incurred a risk of being 'set' at the bottom of the pot, and, re-melting the mass, wasted the zinc. These alloys came out much nearer to their intended weight.

"In making the tin and copper alloys, very little difficulty was experienced. The copper was put into the pot, together with a little charcoal, which was added to assist fusion, and also to cause the alloy to run clean out; as, in pouring gun-metal, a small quantity is usually left on the top of the crucible, which would have been an interference in these experiments. When the copper had ceased boiling, and was at a bright-red heat, it was taken from the fire, and the tin previously melted in a ladle was thrown in; every mixture was well stirred, and poured immediately.

"In the fourteen alloys thus formed, each weighing about a pound and a-half—namely, $\frac{1}{2}$, 1, $1\frac{1}{2}$, &c., up to 8 ounces of tin to the copper (missing $6\frac{1}{2}$ and $7\frac{1}{2}$), no material loss was sustained in nine instances; and in the other five it never exceeded one-eighth of an ounce; and that quantity was probably lost rather in fragments than by oxidation.

"Alloys of 2, 4, 6, and 8 ounces of lead to the pound of copper were made under exactly the same circumstances as the last."

From these carefully-conducted experiments, it is evident that the difficulty of uniting copper and zinc in producing brass, arises from the volatility of the zinc; but that, by proper precautions, the loss may be kept within very moderate limits.

There is another point of considerable importance generally in the alloys of copper with zinc and tin. The latter metals have considerably less specific gravity than copper; and, consequently, there is a tendency, in large castings of the copper descending and settling at the lower end of the mould. Just as in solutions we may so arrange two or three in the same vessel—as, for instance, one of sulphate of copper at the bottom, another of common salts above this, and at the top, distilled water; each being kept as separate from the other as if divided by a diaphragm—so with metals in a state of fusion, there is a tendency to locate themselves according to their specific gravity. Two methods exist to prevent this untoward result, and to maintain the casting homogeneous throughout. The first is, in large operations to pour the contents of each crucible into the mould at the moment the union of the metals forming the alloy seems most complete; and secondly, to make the alloy, allow it to cool, and then to mix different makings together before re-melting. Yet, despite every care, it is exceedingly difficult to ensure a regularity of constitution throughout a large mass.

Copper and zinc form several alloys that pass under other denominations than that of brass, and that are applied to various purposes. The colour, hardness, and malleability of these greatly vary; and all the qualities result, or are modified, by the respective proportions in which the two metals are united. It is impossible to give an accurate table of the proportions always adopted, because they are subject to slight variations, frequently dependent on the fancy of the maker. Amongst many, the following, perhaps, are those best defined. The proportions are given in parts of a pound: sixteen ounces of copper, in all cases, being presumed as the quantity of that metal used, except when otherwise stated.

Table of Alloys of Copper and Zinc.

Zinc.	Copper.	Uses.
Ounces.	Ounces.	
$\frac{1}{8}$ to $\frac{1}{2}$	16	Sound copper castings.
1 to $1\frac{1}{4}$	"	Dutch gold.
2	"	Tombac.
3 to 4	"	Pinchbeck.
6	"	Bristol brass.
8	"	Ordinary brass.
$10\frac{1}{2}$	"	Muntz's metal, so much used for sheathing ships' bottoms.
16	"	Soft zinc, or spelter solder.
5	15	Prince's metal.
8 Brass	16	Pinchbeck.

Besides the above, are alloys of copper or brass, with zinc, tin, and lead, to which we shall direct attention hereafter.

Of recent years, the old copper coinage of the United Kingdom has been called in. Now pence, &c., are made of an alloy of about four per cent. of zinc, with 96 of copper. The impression of the die is sharper, and the wear of the coin is lessened. Another objection to the old copper coinage is also almost removed—it is that of the unpleasant smell which it communicated to the fingers when handled.

A method of producing a brass surface on copper plate is that known as cementation; and in many respects it resembles the process of case-hardening, described at p. 102 *ante*. In the latter operation the surface of the iron is converted into steel by heating it in contact with charcoal, blood, &c. In the process of cementation, the copper plate is coated superficially with calamine and charcoal; and a number of these being piled together, are exposed to heat in a furnace. Gradually the ore of zinc is reduced, and the metal attaches itself to the copper surface, converting it into brass. If the process be long continued, the zinc penetrates completely

into the centre of the copper, whether it be bar or sheet, and thus the whole mass becomes at last converted into brass. Of course this method is not so certain in its results, or proportions of the metal, as that already described ; but it is available for some purposes analogous to such as are found in the method of case-hardening just mentioned.

Copper and Tin Alloys.—Under this head a great number of useful alloys are ranged that have far more numerous applications than those of copper and zinc; for amongst them are materials for bells, guns (now nearly obsolete on account of the improvements made in recent years, in the steel manufacture), bearings for machinery, bronze, speculum metal for telescopes, &c., &c.

It will be unnecessary here to repeat the methods of melting the component metals in each of the various alloys arising from the mixture of copper and tin. One point of importance, however, may be especially noticed; and that is, the extraordinary range of hardness that a varied proportion of the metals produces. Taking the entire range, we may observe that an alloy of one part of tin to sixteen of copper gives a soft metal, readily turned in the lathe, and, generally speaking, very manageable in all respects; but eight parts of tin to sixteen of copper produce an alloy used for the specula of reflecting telescopes, that is so hard as scarcely to be touched with a file ; as brittle as glass, and totally devoid of malleability. This evidences that not only is a great physical change produced by such a union (for both metals separately are very soft), but seems to indicate that a chemical union must take place, the consequence and evidence of which is seen in the physical character just named.

Whilst referring to speculum metal, we may give a short description of the largest casting of the kind that has yet been effected ; that being the speculum of the celebrated telescope made by the late Lord Rosse many years ago. In making an alloy for a speculum many points require consideration. It is desirable that the alloy should be as white as possible, to avoid effects of colour in the reflection from its surface ; but this point is not absolutely essential, because, by a very simple optical contrivance, depending on the laws of complementary colours, any difficulty in this respect may be obviated, and the colour neutralised to the eye. It should be hard, because otherwise the surface could neither receive nor retain a perfect polish—the essential of a good speculum. But although hard, the metal must not be too brittle, or it would most certainly crack during the operation of polishing. And, lastly, the surface, or rather the quality of metal, must be such as not to be liable to tarnish by the action of air and moisture, to which it is constantly exposed when in use. Now these difficulties, one or more, for a long time prevented a successful casting for large specula ; and an almost endless series of experiments were tried, from the days of Sir Isaac Newton until Lord Rosse so admirably succeeded in the attempt. Almost every metal, likely and unlikely, was tried : copper, zinc, antimony, lead, tin, arsenic, iron, bismuth, brass, gold, silver, and platina, alloyed or otherwise, having been used in all manner of proportions. Lord Rosse adopted, as near as possible, the proportion of one part of tin to two of copper ; and used no other metal —a conclusion at which he arrived after many tedious trials. The method adopted for melting the metals, and casting the alloy, was as follows :—

He employed three furnaces, each about six feet square, and eight feet high ; which were built of brick, and properly lined with refractory materials. One crucible was placed in each furnace. The crucibles were of cast-iron, two feet in diameter, and thirty inches deep, weighing about half a ton each. The pouring baskets were of iron, having long handles projecting from one side. The mould to receive the metal was made of iron hoops, laid closely one within another, with their edges uppermost; their edges were all turned in a lathe, so as to give a proper concavity to the surface; and on this surface a bed of sand was worked to scrupulous accuracy of force. The separate metals, in the proportions already named—two of copper to one of tin—fused and broken up, were placed in the crucibles when the latter were highly heated, and then exposed to the fiercest heat of the furnace for nine hours. When ready for use, a crane was employed to draw each crucible out of the furnace, and to deposit it in the iron basket; the three baskets were placed contiguous to the mould; and, at a given signal, they were all tilted up, and the immense mass of fiery liquid metal poured into the mould. In the space of about twenty minutes the cast had cooled, and, being strengthened by an iron hoop, adjusted round its edge, it was dragged out of the mould along a railway to the annealing oven, which was at a dull red heat. Every door or other aperture to the oven was closed; and here the speculum remained sixteen weeks, in order that it might cool as slowly as possible, and so become perfectly annealed. This was absolutely necessary, because of the brittle character of the metal : a sudden cooling of any portion would have as certainly cracked the casting as hot water does badly annealed glass ; and the labour of months would have been thrown away. The speculum so successfully cast was six feet in diameter, five inches thick at the centre, by four and a-half at the edges, and weighed about six thousand pounds before grinding.

Bell metal, gun-metal, and bronze, are terms applied to various alloys of copper and tin, although the constitution of bronze is exceedingly variable, at times having zinc as a part constituent. The bearings of machinery are generally made of an alloy of copper and tin, in varying proportions, dependent on their size, the amount of friction they have to undergo, which is dependent on the weight of the shaft, and the extent of its rubbing surface. Amongst the most important alloys of copper and tin are the following, in which sixteen ounces is the quantity of copper in each case.

Table of Alloys of Copper and Tin.

Tin.	Copper.	Uses.
Ounces.	Ounces.	
1	16	Soft gun-metal.
1½ to 2	,,	Brass guns, wheels, &c.
3 to 3½	,,	Bells of small size, gong-metal, &c.
4 to 4½	,,	House bells of various sizes.
5	,,	Church and other large bells.
8	,,	Speculum metal, as used by Lord Rosse, in the speculum of his large telescope, just described.

Of the above list of purposes to which alloys of copper and tin are applied, their use for cannon has now become obsolete, as already mentioned, in consequence of the substitution of steel by Krupp, Armstrong, Whitworth, and other noted makers of large cannons. This is a subject to which full attention will be drawn in a subsequent chapter on iron and steel manufactures. Gun-metal, however, so called, is used for portions of machinery, as well as other alloys of copper and tin.

Phosphor-bronze is a term applied to an alloy of copper and tin, in which is a certain amount of phosphorus. It is one of the best and most durable metals for bearings and bushes, hydraulic pumps, pinions, valves, &c., also as a material for wire, tubes for locomotive and other purposes, sheet, tools, steam fittings, &c.

Bell-metal is a term applied to a variety of alloys other than that properly appropriate to the founding of bells, on which we may here make a few remarks and give some illustrations, as the subject hardly falls under the general terms of metal manufactures. Bells have given rise to a host of pleasant allusions and similes by the writers of every nation where they have been customarily used. Schiller wrote a "Song of the Bell," which is one of the most spirit-stirring productions ever devoted to manufacture; for, among other matters, the chief steps in making the bell are described by the poet. In many parts of Germany, especially near the Hartz Mountains, the casting of a large bell is made a matter of rejoicing, to which friends and neighbours are invited by the bell-founder; and it seems to be as a sort of joyous account of one of these meetings that Schiller wrote his song. The mixing of the ingredients, the melting, the casting, the cooling—all are described; and at intervals or resting-moments between the processes, the poet indulges in reflections upon the many events of life connected in one way or other with the sound of a bell. One of his stanzas relates to the supply of the furnace:—

"Billet of the fir-wood take,
Every billet dry and sound,
That flame, a gather'd flame awake,
And vault with fire the furnace round.
Quickly cast the copper in,
Quickly cast due weight of tin,
That the bell's tenacious food,
May rightly flow in order'd mood."

In another stanza we trace the melting and purifying of the ingredients:—

"Ha! the rising bubbles tell
Metals mingling, melting well.
Salt of ashes lightly throw—
So the fused ore shall flow.
Quickly from the scum and froth
Cleanse away the whitening froth,
That the metal pure and choice
May swell the full sonorous voice."

The reader will not have much difficulty in calling to mind numerous allusions to the use of the bell as a symbol of death, of rejoicing, of the passage of time, &c. But leaving these, we find that, let the motives have been what they may, bells have been constructed in some countries of most extraordinary magnitude.

The construction of these monster bells was commenced so early as the sixth century; or, at least, it was about that time that the custom became established of placing in the belfries of churches bells large enough to be heard for a great distance. The monks of Croyland Abbey are said to have had a peal of fine bells in the tenth century; they were five in number, and designated by the odd names of Pega and Bega, Tatwin and Turketual, Betelem and Bartholomew. Such bells as these were not only rung for the same purposes as in modern days, but for others which no longer accord with the spirit of the age.

The possession of a large bell by a town, a college, or a church, is regarded as quite a notable feature; and we can easily obtain records of the most celebrated bells. The "Great Tom of Lincoln," for example, which was constructed in 1610, and remained in constant use for two centuries, weighed nearly 10,000 lbs. It was replaced in 1835 by the new "Great Tom," which was 2,000 lbs. heavier. The great bell of St. Paul's weighs between 11,000 and 12,000 lbs., and measures nine feet in diameter. The "Great Tom of Oxford" is larger than any of these three; it is upwards of seven feet in diameter at the rim, has a height of five feet nine inches, is six inches thick at the striking part, and weighs 17,000 lbs. In 1845 a bell was cast for York Minster, which greatly exceeds them all; as it weighs more than 27,000 lbs., is seven feet seven inches in height, eight feet four inches in diameter, and cost about £2,000. A still larger bell was cast, in 1856, for the new Houses of Parliament. Its height was seven feet ten inches and a-half; its diameter nine feet five inches and a-half; and its cost £3,000. It remained at the foot of the clock-tower for several months, the tower not being fit to receive it; and on the 24th of September, 1857, it cracked. Another has since been cast of the same dimensions; and is now familiarly known as "Big Ben."

Yet vast as these bells seem to be, they are insignificant compared with some in foreign countries. In Fig. 135 is a comparative view of five bells, in which their relative sizes are correctly preserved. It will here be seen that the "Great Tom of Oxford" is really a very little Tom when compared with others. At Erfurt is a bell more than ten feet high; at Rouen is one yet higher;

Sir J. Whitworth

while at Pekin in China there is a curiously shaped bell more than fourteen feet high by thirteen wide. But Russia is the great country for bells. The "Tsar-Kolokol" and the "Bolshoi" are the largest bells in the world. It is said 'that Tsar-Kolokol," or king of bells (Fig. 136), contains metal enough to make thirty-six bells as large as the great bell of St. Paul's; the weight being 400,000 lbs. The bell had long been lying in a cavity beneath the tower of the cathedral at Moscow. It was made from an old bell which was destroyed at the beginning of the last century; aided by contributions of metal from royal and noble personages. Nay, it is said that persons in Russia had such a superstitious veneration for this bell, that they brought metal from every part of the empire to add to the store; and nobles vied with each other in casting gold, silver, and trinkets among the melting ingredients. The bell was suspended in the year 1737, from immense oaken beams, but the wood-work having on one occasion caught fire, the bell fell down, and a piece was broken out large enough to admit two men abreast into the interior. Dr. Clarke says that "peasants visit the bell as they would resort to a church, considering it an act of devotion, and crossing themselves as they ascend and descend the steps. The bottom of the pit is covered with water and large pieces of timber; these, added to the darkness, render it always an unpleasant and unwholesome place, in addition to the danger arising from the ladders leading to the bottom."

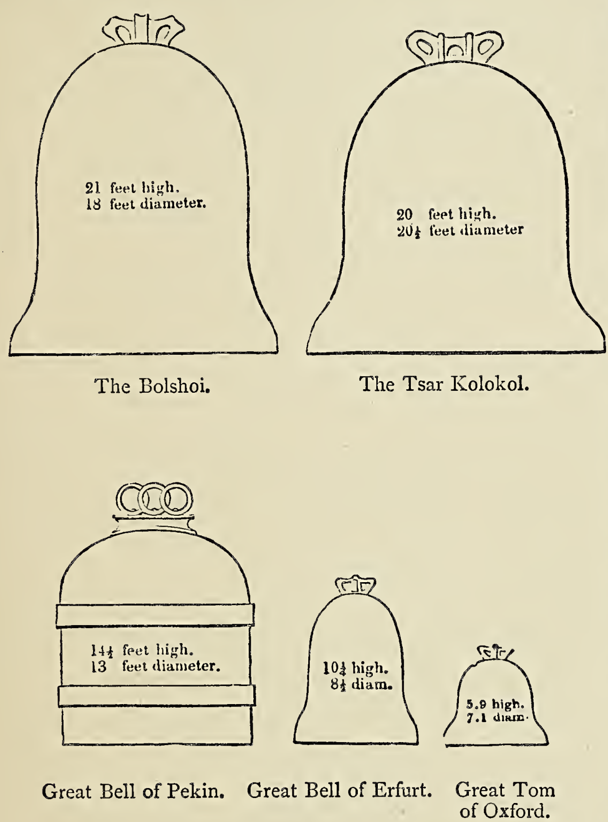


Fig. 135.—Comparative dimensions of celebrated Bells.

Since Dr. Clarke wrote, however, a remarkable enterprise has been conducted, viz., the suspension of this ponderous mass from beams above. Although no distinct evidence of the fact has been preserved, yet it is believed that the "Tsar-Kolokol" was originally suspended, and that the clapper was worked by a number of men by means of ropes, as represented in Fig. 136; and to restore it to a similar position was the object of an ingenious operation conducted in the year 1836; which was thus described in the scientific journals at the time:—"M. Montferrand, a gentleman greatly distinguished in Petersburg by the numerous works he has executed, was intrusted with the direction of the operations. As the bell was lying in a cavity in the ground, and more than thirty feet below the surface, a large excavation was made to clear it. Over this was constructed a strong and lofty scaffold for the attachment of the blocks and for the temporary suspension of the bell at the proper height. At half-past five in the morning, the authorities of Moscow and a large number of spectators being assembled on the spot, prayers were offered up for the success of the attempt, and the operations commenced on a signal given by M. Montferrand. Six hundred soldiers simultaneously set to at a large number of capstans. The enormous weight was mastered, and the bell was soon seen to rise slowly in the pit. Forty-two minutes elapsed during its elevation to the necessary height. No accident occurred. The first operation being finished, the next was to build a platform beneath the suspended bell. This was completed in eight hours, and the bell lowered upon it. On the following day it was placed on a sledge and drawn, by means of an inclined plane, up to the pedestal intended to support it, and there finally left." It is more as a curiosity than anything else that the bell has been raised; for the large hole in it has effectually ruined its resonant quality.

The other Russian bell sketched in Fig. 135, named the "Bolshoi," or large bell, was cast to replace one destroyed by the French during their brief residence in Moscow in 1812. The materials of the old bell, other metal given by the Emperor, and precious metal given by the nobles, were thrown into the casting furnace,

and the new Bolshoi made therefrom. It is about twenty-one feet high by eighteen in diameter, and weighs 144,000 lbs.—an enormous weight certainly; but still far below that of the "Tsar-kolokol." The tongue or clapper alone weighs more than 4,000 lbs. This bell is regularly suspended fit for use; and its suspension was attended with some such a ceremony as in the case of its monster companion:—"On the 3rd of February, 1817, the New Bell was moved with great ceremony on a large wooden sledge from the foundry to the Cathedral; a Te Deum was celebrated, and the labour of dragging the sledge committed to the multitude, who disputed the honour of touching a rope. The movements were regulated by little bells, managed by M. Bogdanof, who stood on a platform attached to the bell. Part of the wall was taken down to admit its passage; and, as soon as it reached its destination, the people leaped upon M. Bogdanof, kissing his hands, cheeks, and clothes, and showing, by every means in their power, the gratitude they felt at the restoration of their old favourite. Some days after this the New Bell was slowly raised to the place of its predecessor, and properly suspended. This bell is said to produce a sound which vibrates all over Moscow like the fullest and lowest tones of a vast organ, or the rolling of distant thunder."

In the manufacture of large bells, a process of casting or founding is adopted, very similar to that followed in other branches of metallurgy. There is first built up a mass of brickwork to form the core or mould, shaped like the bell, but rather smaller than its internal diameter. This is coated externally with a composition of clay or earth; and the damp surface is worked to a true contour and smooth surface by means of gauges or modelling tools, so as to present—both as to size and to device or surface—an exact reverse of the intended interior of the bell. This coating is thoroughly dried in a kiln; and when dry a little tan-dust is sprinkled on it, to prepare it for the reception of a second layer. This outer layer is brought to a surface exactly resembling the exterior of the intended bell. This in its turn being dried, a sprinkling of tan-dust is applied, and a third layer of clay put on, much thicker than both of the others. This is dried, and when dry it is lifted off the previous coatings as a separate cap or cover, which is enabled to be done because the tan-dust prevents the adhesion of the different layers. The second or middle layer is then picked away piecemeal; and the outer case being put on again, there is space existing throughout the whole mould equal to the thickness of the intended bell. It will be easy to see that the object of the three layers of clay is as follows:—the inner one gives the inner contour to the bell; the outer one gives to it the external contour; and the middle one determines the thickness of the metal.

This mould of brickwork is built up in a pit so as to be entirely below the level of the ground in the casting-house. Near the pit is a furnace, with an opening at the top where the metal is thrown, in, and a small orifice at the bottom whence the melted metal flows out when the mould is prepared to receive it. The materials used in the manufacture of bell-metal are copper and tin. Old copper ship-sheathing is very often employed for this purpose. The heat is obtained from dry billet-wood, which is found to injure the metal less than any bituminous fuel. When thoroughly melted the metal presents the appearance of liquid fire; and, on the opening of a small hole at the lower part of the furnace, it gushes out, and flows along a channel to the casting pit (which has been previously filled up with loam to the level of this channel). The metal finds an entrance into certain openings left in the loam, and gradually fills the bell-mould beneath. When the metal has solidified, the mould is pulled to pieces, and the bell finished up by hand. Sometimes many bells are cast together in one pit (as in Fig. 137); there being openings left in the loam above each mould.

Bell-metal, however, like gun-metal, may possibly have its days numbered as a material for bell-founding. Indeed, in 1862, some fine bells were shown at the London Exhibition, made entirely of steel, the latter as in many other cases replacing copper and its alloys.

Lead Alloys.—These may be very briefly dismissed, so far as we can at present deal with them in relation to metals already described—*i.e.*, copper, tin, and zinc. Practically, indeed, lead is chiefly used as a constituent of an alloy only in solder. Two parts of lead, with one of tin, form soft solder; and the reverse proportion of the metals, hard solder. Lead is also used with antimony, as type-metal, with bismuth, &c.; but of these alloys we shall have hereafter to speak in connection with those metals.

We may next proceed to detail some alloys in which copper, zinc, tin, and lead are employed, with metals not hitherto mentioned, and also refer to several mixtures of them, as we have hitherto only considered the metals described as "paired" together.

Copper forms the usual alloy of gold and silver for coin, plate, &c., the details of which will be subsequently entered into in connection with the precious metals. With aluminium, as already stated, copper forms, in various proportions, alloys that so greatly resemble gold in respect to colour, brilliancy, and permanence of polish, as to permit the substitute of this alloy for many purposes to which the alloys of gold had alone been previously applied, especially in imitation jewellery, pencil-cases, &c.

Although generally a soft metal, we have seen that copper, with others even softer than itself, is capable of producing very hard alloys; so hard, indeed, as to equal almost the cutting power of steel. The subject is one, physically and chemically, of great interest, and well deserves extended and careful examination. But the operations required for determining the results, and their causes, are exceedingly tedious in their duration, and at the same time, by no means inviting; for the intense heat, dust, and

dirt of furnace operations, unless a matter of pure duty or business, are not such that many practical chemists or physicists would engage in. The results hitherto arrived at have been rather gained in the workshop, or foundry, than the laboratory.

If, therefore, any uncertainty exists in reference to the choice of exact proportions in mixed alloys; and if, as is usually the case, a great variety of recipes has been given for the production of them, we shall not feel our character impugned for accuracy in presenting the following, extracted from various sources, equally to be depended on, simply because none can claim any precise degree of accuracy. At the same time they may serve as a general guide to those of our readers who may feel disposed to enter on a series of investigations, that, if properly conducted, might prove, in the result, one of the most profitable occupations, in a practical and pecuniary point of view, that any branch of applied chemistry can offer to an enterprising experimentalist.

Mixed Alloys of Copper, Tin, Zinc, and Lead.

$1\frac{1}{2}$ ounces of tin, with $\frac{1}{2}$ ounce of zinc, and 16 ounces of copper, afford a strong and tenacious metal.

$1\frac{1}{2}$ ounce of tin, 2 ounces of brass, and 16 ounces of copper. Used for wheels, &c.

2 ounces of tin, and $1\frac{1}{2}$ ounce of brass, produce a metal good for turning in the lathe.

$2\frac{1}{4}$ ounces of tin, and $1\frac{1}{2}$ ounce of brass. Suitable for bearing-nuts.

$1\frac{7}{8}$ ounce of tin, and the same quantity of zinc. A white composition, generally hard, and may be used for bearings of small size, when a rapid motion is required, as in the flies of a cotton carding-engine, &c.

$2\frac{1}{2}$ ounces of tin, $\frac{1}{2}$ ounce of zinc, and 16 ounces of copper. Good tenacious bearings for small shafting.

$2\frac{1}{2}$ ounces of tin, the same quantity of zinc, and 16 ounces of copper. An alloy so hard as almost to resist the action of a steel file.

1 ounce of tin, 2 ounces of zinc, and 16 of copper, afford hard white button-metal.

$\frac{1}{2}$ ounce of tin, $1\frac{1}{2}$ ounce of zinc, and 16 ounces of copper. A common alloy for buttons.

10 ounces of tin, 6 ounces of copper, and 4 ounces of brass, produce white solder.

The present copper coinage is an alloy of copper and zinc as already mentioned.

The preceding recipes may be of considerable use as a general direction in respect to producing alloys of various degrees of hardness, colour and other qualities. The remarks and experiments already given at p. 129, *ante*, in reference to the methods, apparatus, &c., employed for making alloys, will guide those desirous of pursuing the subject practically, or in producing any of them, or the other alloys of copper, &c., already mentioned.

It may be convenient, at this place, to give an extended table (for which we are indebted to Mr. Barlow) of numerous alloys of metals, the peculiarities or accuracy of which have already been dealt with incidently in the preceding pages, or will subsequently come under notice when we treat of metals not hitherto specifically described.

Proportions of the Constituents of various Alloys.

Gun-metal . . .	1 tin, 10 copper; or 1 tin, 2 zinc, 16 brass.
Bell-metal . . .	6 copper, 2 tin.
Speculum metal .	7 copper, 3 zinc, 4 tin. (See p. 131, on this alloy.)
Bronze	7 copper, 3 zinc, 2 tin.
Bath metal . .	$4\frac{1}{2}$ zinc, 16 brass.
Pinchbeck . . .	16 zinc, 5 copper.
,, .	1 brass, 2 copper.
Prince's metal .	3 copper, 1 zinc.
,, ,, .	4 copper, 2 zinc.
British tutania .	4 copper, 4 tin, bismuth, and 4 of antimony, to be combined with melted tin at discretion.
,, ,, .	16 copper, 16 tin, 32 antimony.
Queen's metal .	9 tin, 1 bismuth, 1 antimony, 1 lead.
,, ,, .	100 tin, 8 antimony, 2 bismuth, and 4 copper.
White metal . .	10 lead, 6 bismuth, 4 antimony.
,, ,, . .	10 tin, 8 brass, 2 antimony.
Hard white metal	2 brass, 3 zinc, 10 tin.
Blanched copper .	16 copper, 1 arsenious acid (common white arsenic).
Printing-type . .	10 lead, 2 antimony.
Small type, and stereotype plate	9 lead, 2 antimony, 1 bismuth; or 16 lead, 4 antimony, 1 tin.
Common pewter .	7 tin, 1 lead, $\frac{1}{2}$ copper, $\frac{7}{8}$ zinc
Hard pewter . .	12 tin, 1 antimony, $\frac{1}{4}$ copper
Best pewter . .	100 tin, 17 antimony.
Solder for steel joints	19 silver, 1 copper, 2 brass.
Silver solder . .	19 silver, 1 copper, 10 brass.
Solder for plated goods	2 silver, 1 brass.
Solder for gold .	12 pure gold, 2 silver, 4 copper.
Standard silver .	37 silver, 3 copper.
Standard gold .	11 gold, 1 copper.
Jewellery gold .	Exceedingly variable.
"Common gold"	3 copper, 1 old brass, $\frac{3}{4}$ tin.
Menheim gold .	7 copper, 3 brass, $1\frac{1}{2}$ tin.
"Gilding" metal	4 copper, 1 brass, $3\frac{1}{2}$ tin.

Chinese packfong, according to Dr. Fyfe, is composed of—

Copper	40·4
Zinc	25·4
Nickel	31·6
Iron	2·6
	100·0

The preceding table of constituents of alloys named is given with all reservation in respect to its accuracy, controlled by what we have

previously stated, and what will have to be remarked as we deal with metals yet undescribed in these pages. At a previous page (see *ante*, p. 102) we have noted the singular anomalies that arise in respect to the specific gravities of some alloys, pointing out, that whilst, in many cases, the specific gravity is less than the arithmetical mean of the constituents, it frequently exceeds that amount. The following table may be considered as illustrative of some results in alloys in respect to lead, tin, antimony, and bismuth, and may not be without its uses; the specific gravities of the metals constituting the alloys being taken as—lead, 11·45; bismuth, 9·82; tin, 7·25; and antimony as 6·80; water as the standard=1·00.

Specific Gravity of some Alloys.

Alloys.	Specific Gravity.
10 lead to 1 bismuth	10·830
2 ,, ,, 1 ,,	11·090
1 ,, ,, 1 ,,	10·931
10 tin ,, 1 antimony	7·359
8 ,, ,, 1 ,,	7·276
6 ,, ,, 1 ,,	7·228
4 tin to 1 antimony	7·192
2 ,, ,, 1 ,,	7·105
1 ,, ,, 1 ,,	7·060
10 ,, ,, 1 bismuth	7·576
4 ,, ,, 1 ,,	7·613
2 ,, ,, 1 ,,	8·076
1 ,, ,, 1 ,,	8·146
1 ,, ,, 2 ,,	8·580
1 ,, ,, 4 ,,	9·009
1 ,, ,, 10 ,,	9·439
10 ,, ,, 1 zinc	7·288
2 ,, ,, 1 ,,	7·000
1 ,, ,, 1 ,,	7.321
1 ,, ,, 1 ,,	7·100
1 ,, ,, 10 ,,	7·130

Having thus reviewed the leading facts relating to alloys of copper, tin, lead, and zinc, we may briefly draw attention to their most prominent uses, so far as they have hitherto been unnoticed; for we have incidently been compelled, by the very names that have been employed to designate some of them, to enter slightly on their applications.

Generally speaking, sheet copper is that form

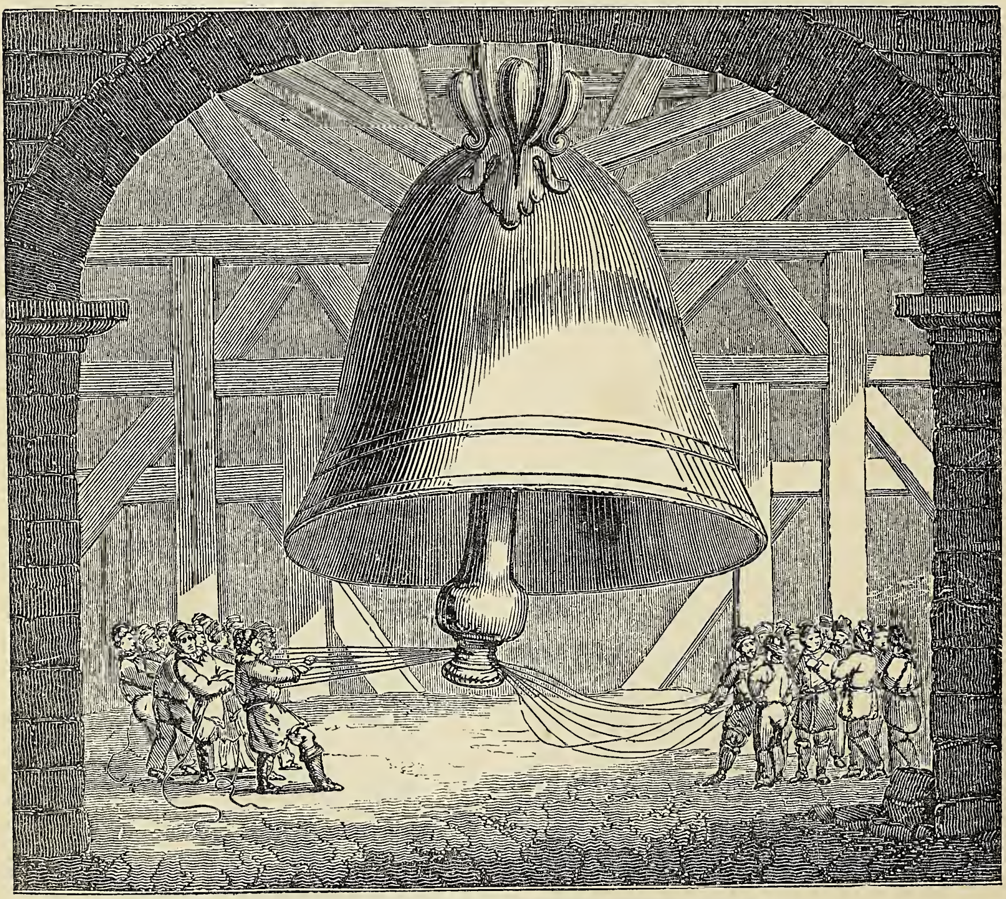


Fig. 136.—"Tsar-Kolokol," or King of Bells, at Moscow.

of the metal most used for making vessels of all kinds, from the pan of the sugar-refiner to the stew-pan of the cook. As already stated, the thickness is varied by the extent of rolling to which the metal is subjected; and this is judged of, in commerce, either by the gauge or by the weight per square foot. Thus copper sheet may be purchased at from one to many pounds' weight per square foot. Some years ago, copper sheet was employed for making boilers for steam-engines; but that use of the metal has long become obsolete, owing to the much higher character that modern manufactured iron and steel now bear in respect to their tenacity. The largest vessels now made of copper are those employed for sugar-refining, according to the vacuum process; and these are sometimes of great capacity, some specimens of which were shown in the machinery department of the Exhibition at London, in 1862. Distillers, brewers, and other businesses in which large quantities of liquids are required to be heated, consume much copper sheet in the construction of the necessary vessels. Copper has the advantage of being an excellent conductor of heat; and hence is, to some extent, free from the danger of burning liquids boiled in it. In cases where large circular portions of metal are required, the curve is given by means of a kind of tilt hammer, which reduces the metal approximately into the desired shape. Except in rare cases casting is not had recourse to, because copper is not only in itself a tenacious and expensive metal, but, as the "film," or sheet, need not be very thick, it would be impossible to cast it evenly. Hammering is one of the chief operations of the coppersmith, to bring the material into proper shape. By this process, not only is the metal curved into the desired form, but, at the same time, it is rendered more dense and tenacious, and, therefore, better fitted to resist any pressure or strain to which it may be subjected. The sheet is placed on an anvil, and then hammered smartly in all directions—an operation technically known as planishing. Pieces or sheets of copper so shaped, of course only form part of a vessel; and these are joined together by riveting. The edges either overlay or are flanged. In either case holes are punched or drilled through the collar or lapped edges; and into these rivets are inserted, which are really but short, thick, pointless, but wide-headed copper nails. The end of the rivet without a head is then beaten down to form one; and thus the sheets or other masses of rolled and hammered copper are fastened together. Riveting is always adopted in vessels that have to sustain either much weight or pressure: but "brazing," a modified form of soldering, is substituted when a simple joint, not necessarily strong, is required. Of course, brazing is a much more expeditious method, and is generally adopted in making copper and brass pipe. The flux to remove oxide is generally borax. The methods of mak-

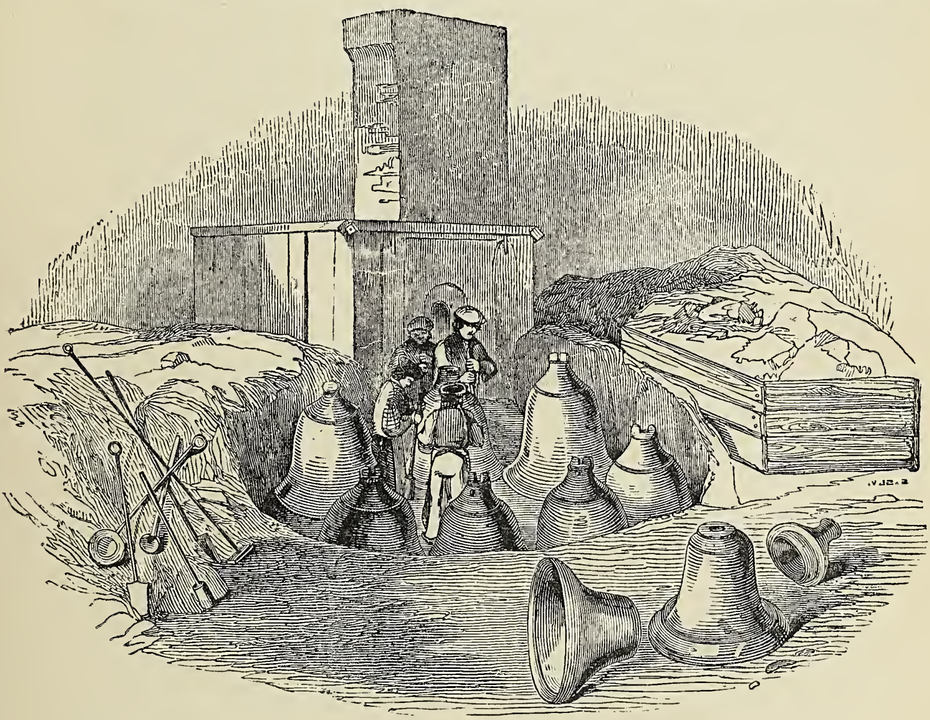


Fig. 137.—Casting-pit of a Bell-Foundry.

ing large and small vessels of copper are equally the same; planishing, riveting, or brazing being the chief operations. Generally the inside of such vessels is coated with tin, to preserve them from the action of acid and other liquids passing through or over them—a precaution that we have already pointed out as being of the utmost importance to be well done in every instance in which copper is employed as a material for making vessels used to cook food, &c., as the metal, in all its combinations that are soluble, is deadly poisonous. The interior of a large coppersmith's or brazier's is illustrated at page 140, Fig. 138.

A large quantity of copper is used in making wire. Wire-making, or "wire-drawing," as it is more usually termed, is but an extension of bar-iron rolling, so far as concerns the gradually lengthening and attenuation of the metal; but the effect is brought about by different means. In "rolling," the metal is made red-hot, and is in that state drawn between rollers; whereas in "drawing," the metal, while yet cold, is drawn through a hole somewhat smaller than the bar or rod in diameter. There are, however, many curious points in the mode by which the effect is produced. In early times, when wire or narrow strips of metal were hammered into the form of thin plates, these plates were cut up into narrow ribands, and the ribands were either hammered or filed into a roundish form. At a later period the "drawing-iron" was invented, by which the metal was brought to the required state by drawing it through a hole; but the rods were produced by a laborious process of hammering before the drawing commenced; and it was not till the combined processes of "rolling" and "drawing" were adopted, that wire could be made as in the modern method.

The rods of metal for wire are wrought by the rolling-mill to the thickness of about a sixth of an inch; they are twisted round into coils; and these coils are well washed in sand and water, to take off all dirt and impurities from the surface. In the best wire-drawing establishments at the present day the arrangements are such as are sketched in Fig. 139. Several cylindrical drums or barrels are ranged in two rows on a work-bench, each fixed on a vertical axis, and all being enabled to rotate rapidly by straps and bands from a steam-engine. Close to each drum is a "draw-plate," which consists of an exceedingly hard plate of steel with a well-drilled hole or holes in it. Supposing there are twelve drums in one series, the plates connected with them have holes of twelve different sizes, through most or the whole of which the wire is made to pass during its formation. Following a coil of iron or copper rod through its successive stages of progress, we should find that it is hung on a peg near the drawing-bench; and one end, being uncoiled and filed thin, is inserted into the largest hole in one of the draw-plates. The drum is then made to rotate, by which the metal is forced through the hole, its diameter reduced, and coiled round the drum. It is then removed to a drum and plate having a hole next smaller in size, through which it is drawn. And so on through a great many different stages; the diameter of the wire being decreased and the length increased at each stage. The number of holes through which the wire is drawn depends on the diameter required to be obtained; and this diameter, for iron wire, varies from about one-fiftieth to three-tenths of an inch. This gradual reduction requires much tact and management; for if an attempt were made to draw the wire through a hole of much smaller diameter than itself, the wire would break. Even when the proper sized holes are used, the wire becomes so hard and brittle by the compression that it requires several annealings during the operation. This annealing is done in a curious way. There is a large oven or cell, three or four feet in diameter by eight or ten deep, and in this the coils of wire are placed to be annealed by heating. By placing small coils within the larger ones, as many as twenty or thirty cwt. of wire can be placed in the kiln at once. The kilns are made of iron, cased externally with brickwork; and when the wire is put in, every aperture is closed, the fire is kindled beneath, and a great heat is excited. The gradual cooling from a high temperature has the effect of annealing the wire, and it is then in a fit state to be drawn through the plates. Iron which has been smelted with charcoal instead of with coal is found to bear the greatest amount of drawing without annealings. Copper, from its great tenacity, is easier and oftener drawn without such repeated annealing. We have seen platina wire drawn to a fineness not more than the thickness of a human hair.

Brass is used for a greater variety of purposes than copper, because of its keeping a better polish; and also on account of its rich yellow colour. Many of its uses are familiar to our readers. For its general purposes it is cast, rolled, beaten, drawn into wire, and generally undergoes the usual operations to which all ductile and malleable metals are subjected to prepare them for use in manufactures, the arts, domestic life, &c. The trade of Birmingham is largely constituted of brass manufactures; and the articles manufactured there are too well known to require either description or enumeration. For the better kinds of clocks, brass works are used; and these are first cast in moulds, and afterwards filed and polished. Brass ornaments are, if thin, beaten out of the sheet; or, if thick, they are cast in moulds. In all cases great economy is followed in the use of the metal; for although not so tenacious as copper, it can keep its shape much longer, and is not so liable to be "dinted" by a blow. Bronze, as the material, but more rarely "bronzed" brass, is much employed for such purposes as refer to ornament; and the external surface undergoes various processes to enable it to retain its colour.

Pins.—An immense quantity of brass wire is used for making pins, which are tinned or whitened by boiling them in a solution of cream of tartar and metallic tin, the latter being by electro-metallurgical action thrown down on their surface.

"There are various ways of imparting to articles of brass, or bronze, an external beauty of finish, which the metal, in its original state, would not present. Some articles of real bronze have an artificial *verde antique*, or old green tint imparted to them, by a composition applied to the surface after casting. Some have a warmer or browner tint; while others are touched on the projecting parts with a gold-coloured powder, which gives a peculiar metallic appearance; but this latter expedient is adopted chiefly when figures or ornaments of plaster are coloured to look like bronze.

"Brass-work is brought to a brilliant yellow appearance by the process of lacquering—a process now conducted so skilfully, that the lacquered article presents a very close resemblance to those which have been gilt. When any of the countless articles of brass which Birmingham produces have been formed by casting, drawing, stamping, chasing, or other mechanical operations, they are cleansed from grease by being heated, then laid to steep, or pickle, in dilute acid, and brushed well with a wire or other hard brush. Each article is then dipped separately into aquafortis (weak nitric acid), by which means it speedily acquires a clear, bright yellow colour, wholly free from specks and stains; indeed, it is the remarkably neat and clear-coloured appearance of the small brass goods which has given Birmingham so much celebrity for them. The cleansed and brightened article is then washed in water, dried in hot sawdust, and then burnished on some or all parts of its surface, according to the pattern and object. The burnishers are made of bloodstone, such as is used for burnishing buttons; and the mode of proceeding is exactly similar to other metal-burnishing, the article being held in the hand, or down upon a bench, or in a lathe, according to its shape and size, whilst the burnisher is pressed or rubbed against it.

"The brightened and burnished article of brass receives finally a depth and richness of tint by the process of lacquering. Lacquer is a liquid composed of spirits of wine or methylated spirits (now chiefly used as being much cheaper), gum-lac, tumeric, saffron, &c.; the latter being used for the sake of imparting colouring matter. The brass-work is made clean and hot, and it is in that state coated with a layer of the lacquer, either by dipping or brushing. By heat the spirit is evaporated, leaving a glassy surface on the brass that protects it from the action of the air, and imparts a glossy appearance, together with rich colour."

Copper was formerly much used to sheath the bottom of wooden ships, but has been, of late years, replaced by Muntz's metal—a kind of brass, described, in respect to its constitution, at p. 130, *ante*. Its object is to prevent the adhesion of molluscous animals, barnacles, weeds, &c., that greatly impede the progress of a vessel that has been long at sea. The enormous cost to our national and commercial marine, arising from the diminished speed of ships, and the necessity of cleaning the bottoms at short intervals, can scarcely be imagined. It was stated, at the meeting of the British Association at Nottingham, in 1866, when the subject of another invention to prevent the fouling of ships was under discussion in the Mechanical section, that the barnacles, weeds, &c., that grow on the bottom of some steam-vessels, exhausted three-fourths of the power of the engines; that is, so much force was lost in propelling the vessels, in overcoming the resistance which such adhesive matter offered to their passage through the water. As an instance of this, we may state that the first-class mail-steamers, running between Holyhead and Kingstown in Ireland, have to be laid up once every six weeks, to be cleansed of such adhesion. When the bottom of the vessel was clean, the paddles made 4,700 revolutions to complete the journey; whilst in the last journey, before cleaning, they made 5,700 revolutions to effect the same result. In many cases of large war-vessels, as much as from 3,000 to 4,000 horse-power is lost, owing to the resistance caused by weeds, &c. The great iron-clad, the *Warrior*, has lost 2,000 indicated horse- power, on certain occasions, when tried. The *Great Eastern*, when cleaned, loses many tons of such barnacles, &c., and the labour consumes much money and time. Now, although the preceding facts are drawn from experiments with iron vessels, still precisely the same results occur with those of wood. The metal sheathing prevents this adhesion; for after a small quantity of the weeds, &c., have adhered to its surface, they break away, and leave the bottom clear. Hence formerly. when wooden vessels alone were built, the best class were, and are still, "copper-bottomed." In this application great quantities of the metal were formerly used; but the almost universal replacement by iron and steel for wood in building vessels, much diminishes this method of its application.

Most of the other uses of copper alloys have been previously named, as in the form of gun, bell, and other metals; and hence it will be unnecessary for us to further enlarge on the subject. But immediately in connection with the preceding remarks, we may here take notice of certain applications of zinc, one of the most important of which promised to be a protective action on the bottoms of iron ships, hitherto left at the mercy of all adherent animal and vegetable matter, to the deterioration of the plates, their rapid wearing away, and the loss of speed of the vessel, striking instances of which have just been given.

At the meeting of the British Association, in 1866, Mr. Daft communicated some very interesting results he had obtained in applying zinc as a protection of iron submerged in the sea. It will be remembered that, many years ago, Davy tried numerous experiments to prevent the loss of copper that arose from the success it had in preventing the adhesion of weeds, &c.; for although the metal was quite effective, yet, of course, some portion of it was taken away by every weed or animal that broke from it: the point of its success, in fact, laid in its being readily acted on by the saline

matter of the ocean. His method of protection was that of applying partially zinc plates here and there on the copper surface, and so producing a galvanic action, that transferred the chemical action of the saline matter from the copper to the zinc. He succeeded in thus protecting the copper; but, in so doing, he removed all its efficacy; for the mollusca, &c., very soon again coated the bottom of the vessel, and rendered the copper bottom of course, only an additional and useless weight to the ship's tonnage.

Mr. Daft's plan is, in principle, exactly that of Davy's; but in practice, and in its application, it has an opposite result. Making, as Davy did, the bottom of the vessel negative, electrically speaking—which is equivalent to stopping all chemical action on it by the saline matter—he so coats the iron, that all the barnacles, &c., shall attach themselves to the zinc that he affixes to it as a kind of sheathing. Now, of course, although there is the loss of the zinc constantly going on to a minute extent, as each barnacle, mollusc, or weed breaks away; still, as its cost is so much less than copper, the expense is much less as a constant charge. But, in protecting the iron, he saves the vessel; for if an iron plate wear away off an iron vessel, or its rivets be worn away, the safety of all is endangered; whilst the loss of any number of the metal plates of a wooden vessel becomes merely a question of cost and inconvenience. By direction of the authorities at Portsmouth, pieces of iron thus protected with zinc were submerged in the sea-water of the harbour, for a period varying from ten to sixteen months. On being taken up, the iron was found to be quite free from corrosion, and perfectly clean. Not a barnacle, weed, nor mollusc had adhered to it; and, as far as appearance could indicate, it seemed that little action had taken place on the zinc. Of course, such a result is of the greatest value, although, at present, not verified on the large scale. At all events, the place at which the experiments were carried on, certainly afforded a severe test of its value; for whilst, in the open sea, the water is what may be properly called "salt water," in a harbour a large amount of sulphuretted hydrogen, arising from the bilge (decomposition of organic matter), is constantly present; and it is a chemical compound that acts most rapidly and destructively on all the ordinary metals—in fact, nearly every metal, with the exception of gold and platina. The uses of zinc for "galvanising" iron will be noticed in a subsequent chapter on iron and steel manufactures.

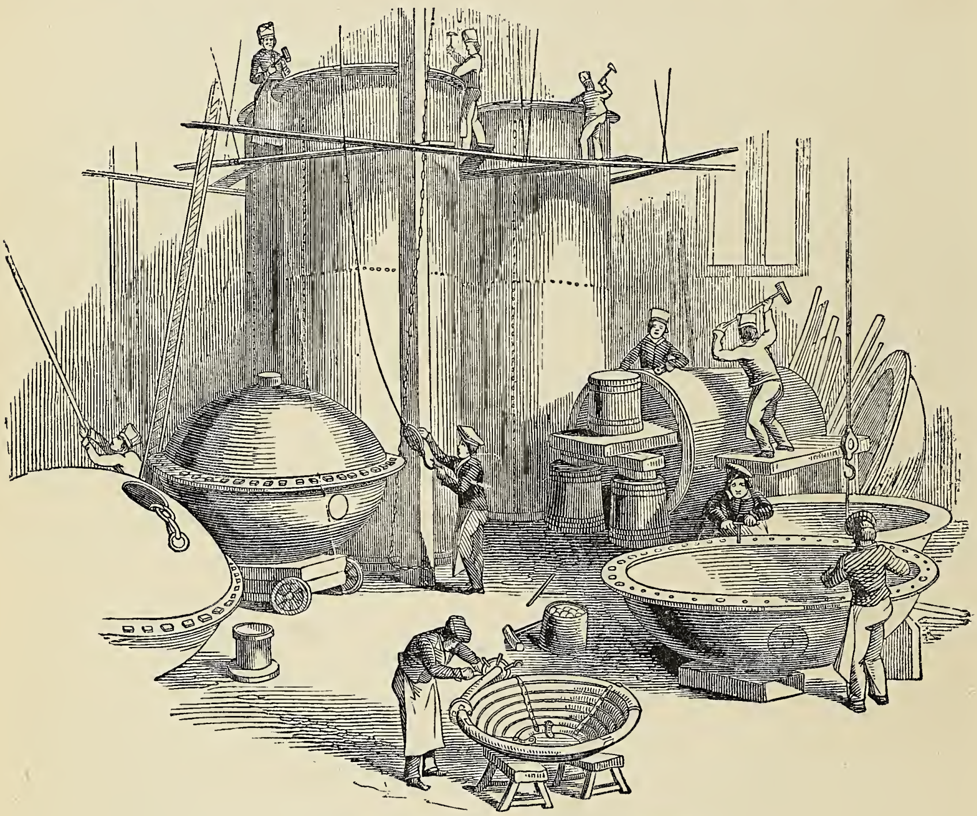


Fig. 138.—Manufacturing Copper Vessels.

Lead, in its numerous applications, is familiarly known; and to some of them we have already alluded; as, for example, sheet, pipes, solder, linings for cisterns, roofs, &c. An important use is that of making shot, in the manufacture of which a considerable amount of science is involved. The lead, after melting, with the addition of a small quantity of arsenic to impart hardness, is dropped, from a considerable height, into cold water. As it falls it attains the form of nearly spherical drops. But the whole mass does not so fall; and hence an ingenious plan is adopted, by which all the round shot run, by their own impetus, down an inclined plane, into a receptacle; made in sheets of any length, and from a thickness varying from that which gives a weight of from four to ten ounces per square foot, at the rate of twenty linear feet per minute. Formerly the method of forming the sheet was exceedingly slow. The pigs were first melted, and then cast into a thick sheet. This was then transferred to rollers, through which it passed several hundred times before it attained the requisite degree of thinness.

Tin, as previously intimated, is too soft to be employed in the form of sheet or wire, excepting foil, in which it has many uses. As a cover to other metals, in the form of tin plate—that is, iron coated and penetrated by tin—it is

Fig. 139.—Wiredrawing Machines.

whilst those whose form is not exactly round cannot traverse the same distance. The latter are re-melted, and again undergo the process just described; whilst those whose shape is perfect are sorted into different sizes, polished in a revolving vessel by blacklead, and so become fitted for commerce. Formerly leaden pipes were cast in a mould; but now very ingenious apparatus is used for drawing them, and also for rolling lead into sheet. At the International Exhibition of 1862 in London, a coil of lead foil, stated to have been one mile long, was exhibited by the Metal Foil Company, produced by a process invented by Mr. Wimshurst. By his method lead can be

largely manufactured, and forms the material of a great number of domestic and other utensils. Its manufacture will be described in a subsequent chapter. Its protective action on copper vessels has been already noticed as essential to their safe use in the preparation of food, &c. In pewter tin is a most essential constituent; and to introduce a small portion of copper to improve the hardness of that material, *temper* is used, already referred to at p. 122 *ante*. It is an alloy of two parts of tin to one of copper. At p. 132, many alloys of tin have been already named, besides those with copper; such as bronze, speculum, bell, and other metals previously described.

Lastly, we may notice some of the chemical combinations of the metals with which we have been dealing, and, in part, previously mentioned in very general terms. Whilst iron, in chemical combination, has but few uses, the chief being that of its sulphate and acetate for dyeing purposes, and both of limited use in medicine, the chemical compounds of copper, tin, &c., have an important and extended influence in our arts and manufactures. The oxides of copper are used in staining glass; the sub, or red oxide, affording all tinges of red; and the proto, or black oxide, producing a fine green. In the chemist's laboratory, the black oxide is of great importance in the analysis of organic bodies. The sulphate of copper, the blue vitriol, or bluestone of commerce, is employed largely in electro-metallurgy, dyeing, and for other purposes. United with arsenic, as an arsenite, copper affords the pigment known as Scheele's green, produced in dyeing, and used in printing paper for ornamenting walls—an application that has long been considered as dangerous; for particles of this compound of arsenic and copper readily spread as a fine dust in a room, and are inhaled, to the danger of all present. Of a still more dangerous character is the application of this compound to colouring ladies' dresses, and the leaves of artificial flowers. In these forms the use of the pigment is positively wicked; for it by no means unfrequently happens, that one individual may carry about in her dress, &c., as much arsenic as would, if taken internally, destroy the whole of the members of the "party" present in a ball-room; and, at every motion of the dress or flowers, particles of arsenic and copper are thrown off into the air. It has frequently happened that the young ladies in a milliner's room are poisoned, and more or less seriously injured, in making up one of these fashionable but poison-carrying dresses. Paper-hangings containing this green are equally dangerous. Verdigris is an acetate of copper, used as a colouring agent or pigment.

The chemical compounds of zinc are of extremely limited use: the oxide, as previously mentioned, being substituted, in house-painting, for white lead; and the sulphate is medicinally employed in solution as a cooling lotion and as a disinfectant. Its ordinary salts being all colourless, renders them of little application in the arts.

Tin, on the contrary, is of much use; its solution in nitro-hydrochloric acid affording the spirits of the dyer, who employs the metal as a mordant, with a large number of vegetable and some animal infusions. The reds and yellows of barwood, Brazil-wood, quercitron, &c., are thus fixed on textile fabrics; but the discovery of the aniline dyes has much lessened the use of these colour-woods, and doubtless will eventually supersede them entirely. Mosaic gold is a compound of tin with sulphur, and may be procured by heating together twelve parts of tin, six each of sal-ammoniac and mercury, and seven parts of flowers of sulphur. All but the sulphide of tin sublimes by heat, and it is left as a solid residue, of a golden colour. With terchloride of gold, the protochloride of tin affords a rich purple, called the purple powder of Cassius, employed in painting china-ware. Oxide of tin affords putty-powder, used for polishing; and it is also employed in enamelling. An amalgam of tin with mercury is the reflecting metal that constitutes the efficiency of modern mirrors, looking-glasses, &c. A sheet of thin tin foil is pressed on a clean surface of glass, and mercury is spread, by means of a hare's foot, so as to coat all the back of the foil. By pressure the two metals unite, and adhere to the surface of the glass, affording a brilliant and permanent reflecting back to it. Stannic acid, or binoxide of tin, forms salts, of which the stannate of soda has uses in the art of calico-printing, &c.

The chemical compounds of lead are of great importance in the arts. The red oxide, or red lead, is a valuable and much-used pigment; as are also massicot and litharge, the former being the protoxide heated short of fusion; whilst the litharge is made by fusing the oxide. The latter substance is of great value in producing drying oils, by being boiled with linseed and other oils, converting them into a kind of resinous condition; and hence, also, employed in making varnishes. White lead is a carbonate of the metal, prepared by slowly acting on the surface of thin lead sheet by weak acetic acid vapours, whereby an acetate is first formed, that is subsequently converted into the carbonate or white lead. This substance used as a pigment has the property of turning black wherever sulphuretted hydrogen is present; hence the spoiling of white paint in places where the smell of drains has access. The oxide of zinc, just described, does not so change; and hence has been substituted, for this and other reasons, for white lead, but has not been successful for reasons already explained. Baryta has had better success as a substitute for white lead. Chrome, or chromate of lead, is also a valuable pigment, naturally of a yellow colour, but also convertible into an orange. As a powder, or in cake, it is used in painting: precipitated by the action of bichromate of potass on acetate of lead, it is largely used by dyers. The acetate, a solution of lead in acetic acid, is commercially known as sugar of lead, and so called from its sweet taste; hence the frequent occurrence of fatal results where it has been carelessly left about. It is used as dryers by painters and varnish-makers; in dyeing, and in medicine; being familiarly known as the basis of the cooling lotion employed, in pharmacy as *Goulard's Solution.* Another and extensive use of lead, in the form of oxide, is that of making flint-glass. It gives density and brilliancy to the glass, and also greatly adds to its fusibility in the pot, making the "metal," as melted glass is termed, work easily, and to soften at a moderate heat.

These varied uses of copper, tin, and lead, independent of their qualities of a metallic nature, result from the readiness with which they enter into chemical combination with oxygen, chlorine,

and other agents already named, and which essentially distinguish them from what are called the "precious" metals, an extended description of which will immediately succeed the present chapter. The value of the latter metals, to a very large extent, depends on their resisting such chemical action; in gold, completely; and in respect to silver, nearly so—at least so far as all ordinary chemical means produce it. The "base" character of iron, copper, zinc, and lead, as they were formerly esteemed by the ancients and alchemists, is not only in our day a redeeming quality, but actually places at our disposal a very much larger number of uses than their simple metallic nature would permit. The processes adopted in modern times, thus tend to enlarge the applications of these bodies, and greatly enhance them as a raw material.

In the uses of the compounds of these metals, other than alloys, we cannot but notice the great value that has arisen from the application of the principles of chemical science, not only in their manufacture, but attended generally by a gradual reduction in price. Yet it must not be forgotten, that such uses as we have described have been long known, and, indeed, have been extensively adopted, in some cases, for centuries. However ridiculous the theories of the alchemists, the practical results of their investigations must not be forgotten; for, in numerous instances, we are indebted to them for valuable discoveries of various compounds now used in the arts, and by processes that they first found out. Some hundreds of years ago, it was known by them, that a piece of polished iron dipped into a solution of sulphate of copper, became, as they thought, converted into the latter metal. We find that it is only replaced by copper; but, practically, we turn the fact into account by throwing our waste iron pots and pans into a stream containing that salt, and so reduce the copper at little or no cost, but to much profit. The difference between alchemy and modern chemistry may generally be defined as that of crude theory contrasted with practical science; so, whilst they thought or fancied, we are sure, and work and utilise with the same materials and with certain success.

We must, however, remark, that the great advance which has been made in the purity and other qualities of most chemical productions, has chiefly arisen from, and been stimulated by, the enormous demand that exists for them at the present day, and which has induced the investment of capital, by means of which many difficulties have been overcome, that, in former days, for want of money and enterprise, were insuperable. Whenever such productions are made on the large scale, they are constantly improved, both in regard to the economy, purity, and methods of manufacture. New modes are devised as fresh demands arise; the energy and genius of invention is stimulated; and a partial benefit frequently becomes converted into a universal good. These observations, although generally applicable to all branches of manufactures dependent on the applications of chemical science, are especially so in relation to such as are connected with metals. Owing to their colour, and other properties, their uses are not merely confined to useful, but also ornamental purposes. Thus whilst, in the days of the alchemist, the salts of copper, tin, and lead were only curiosities, now they are essential to the dyer, calico-printer, glass-stainer, painter, artist, paper-stainer, and a host of other applications not dreamt of when first discovered. As we just now remarked, practical application of science, rather than fanciful theorising, is the characteristic of modern philosophy. This subject will again come under notice under the head of Chemical Manufactures, when the chief carried on in the country will be described.

We here conclude the description of those metals that, with the exception of zinc, may be considered as indigenous to our islands; and to the working of which so much of the prosperity of this country is due.

CHAPTER V.

GOLD, SILVER, MERCURY, PLATINA, ETC.

IN the language of alchemistry, and that of the older chemists, the metals that have hitherto been considered, were termed "base;" for no other reasons, certainly, than that they gave a vast deal of trouble in their reduction from the ore; were, and still are in common use; plentiful, and hence susceptible of constant change in value. Not so with gold and silver. Mankind, from the earliest ages, has considered them as "precious metals," "perfect metals," although they are the most useless for every object, except as a medium of exchange, and for ornamental purposes. That scarcity has always been considered as an element of value is evident; for we have shown, at p. 127, *ante*, that at one time, what may be called native brass, held an intermediate place, general in estimation and pecuniary value, with gold and silver.

At the same time it must be admitted that gold and silver have certain qualities which place them much beyond the rank, chemically speaking, of the ordinary and more universally used metals. In respect to gold, it is barely acted on by any chemical agent, its only solvent being nitro-hydrochloric acid, or, as it has been long known in metallurgy, *aqua regia*. After the lapse of ages, gold scarcely acquires any tarnish; never, if perfectly pure—a fact evident in the numerous specimens of large nuggets that have been collected in so many parts of the world. Silver, on the contrary, although not changed externally by air or moisture, is quickly tarnished by the presence of sulphur vapour, or gases containing sulphur; so much so, indeed, as gradually, under ordinary circumstances of household experience, to gather on its surface a black sulphide, that necessitates constant cleaning. Still, like gold, it is barely acted on by any ordinarily occurring agent, with the exception just named; and hence becomes of much value for producing coin, plate, and plated articles.

History would seem to indicate that, in the early ages of man's existence, gold and silver were exceedingly plentiful; but it must be remembered that, in such times, the possession of the precious metals was confined to few hands, whilst at the present time they are universally distributed. The coin of our day, in civilised countries, absorbs, annually, millions in value of gold and silver, universally current, and of absolute necessity in even the smallest commercial transactions. But besides this use of the precious metals, we must notice the great amount that is annually, and has for centuries past, been converted into what is generally termed "plate," articles of which, in some form, may be found, at least in our islands, in almost the poorest habitations.

In ancient history, accounts have been given of almost fabulous amounts of gold and silver being employed for decoration, and other purposes. The Temple of Solomon, as described in Holy Writ; the golden statues of heathen gods (and, by the way, we are strongly of opinion, from the then great value of brass, that many such objects were made of that material); the riches of Persia in gold, &c., as thrown open by the expedition of Alexander, who took good care to possess himself of as much as could be carried away; with many relations or legends of Arabian-nights'-tales gorgeousness, lead us to suppose that, in such times, gold and silver were abundantly applied for purposes that we should now consider absolute and shameless waste. We read that, at Ecbatana, there was a palace, "so magnificent in every part, as to give a great idea of the power and wealth of those by whom it was created; for, although the wood of it was all cypress or cedar, no part of it was left naked; for the beams, the roof, and the pillars that supported the porticoes and peristyles, were all covered with plates, some of silver, and some of gold. The tiles, likewise, were all of silver. Though the place had been three times plundered, there still remained, in the Temple of Ena, some pillars cased with gold, and a large quantity of silver tiles laid together in a heap. There were also some few wedges of gold, and a much greater number of silver." After perusing this magnificent account of the riches of the temple, we can but come to the conclusion, either that the thieves who plundered it were bad hands at their vocation, or that, in the absence of steam-vessels and railways, they had not sufficient means of transporting the treasures that must have glittered in their eyes, and excited the cupidity of their evil hearts.

But instances of gorgeous display of precious metals and jewels have not been confined to ancient times: in modern days they are by no means uncommon. We have seen an Indian prince prepared for presentation at a *levée*, with something approximating to £150,000 worth of jewels decorating the person; and the sale some years ago of the Esterhazy collection, is another instance in which one individual had gathered together gems of literally fabulous value, simply because, at the nominal market-ruling price, a

purchaser could scarcely be found for such costly objects. As before remarked, however, rarity not only enhances price, but also the fashionable and accidental esteem of an object; and such sentiments always having been, and still equally prevalent, prove that civilisation and common sense have still a very extended field of operation in forming a "stable mind" amongst the human race at large.

But amongst savage nations we find a much more reasonable appreciation of real value in an object, especially one of a metallic character. On the coasts of Western Africa, before the natives knew the factitious value of gold, imposed on it by Europeans, a knife, or even a rusty piece of iron, could be readily exchanged for a considerable quantity of gold. "When Brazil was first discovered by the Portuguese, the inhabitants used fish-hooks of gold, but had no iron, although their soil abounded with that metal. The people in Hispaniola and Mexico were, in like manner, unacquainted with iron when first visited by the Spaniards, though they had both ornaments and implements of gold, and weapons of copper; which latter, as we learn from the analysis of Humboldt, they had acquired the art of hardening by an alloy of tin. This subject has been illustrated in Denmark by opening many Scandinavian tumuli, of very remote ages, from which have been collected specimens of knives, daggers, swords, and implements of industry, which are preserved and arranged in the Museum of Copenhagen. There are tools of various kinds, formed of flint, or other hard stone, in shapes resembling our wedges, axes, chisels, hammers, and knives, which are presumed to have been those first invented. There are swords, daggers, and knives, the blades of which are of gold; whilst an edge of iron is formed, for the purpose of cutting. Some of the tools and weapons are formed principally of copper, with edges of iron; and in many of the implements, the profuse application of copper and of gold, when contrasted with the parsimony evident in the expenditure of iron, seems to prove, that at this unknown period, and among the unknown people that raised the tumuli which antiquarian research has explored, both copper and gold were much more abundant products than iron."

But there is scarcely any part of the world which has been inhabited, that the same remarks do not apply. The opening out of commerce with Japan, subsequent to that effected by Lord Elgin, several years ago, with China; the relics of India, Arabia, Africa, most parts of Europe, not excepting our own islands, and also many parts of continental America, indicate an ancient, extensive, and long-continued use of gold, for ornament chiefly in civilised, but for ordinary uses in savage countries.

In treating of the metal iron, we have stated that it is on that metal our richness, as a nation, has been founded; and it is a remarkable fact, that those nations that have possessed, or still possess it in abundance, are the most prosperous. This arises simply from the immense variety of useful purposes to which it can be applied. On the other hand, nations most "highly favoured" with gold, once rose in barbaric splendour, but since have subsided to political mediocrity, if not to financial bankruptcy—an instance of which, in Europe, will readily present itself to the judgment of our readers in a country that has been often plunged into political, social, moral, and commercial degradation. That certainly proves the love of money to be the root of evil.

In respect to silver, it is found that the present relation between its uses and value, with those of gold, has not always existed. Indeed, whilst, with the exception of iron, gold is the most diffused of all the ordinary metals, silver is much more restricted, and always has been, in its general and geological distribution. But this question we shall more particularly enter into shortly. In other respects, the observations that have been made in regard to gold, are, with certain limitations, applicable also to silver.

It will be noticed that we have included mercury, or quicksilver, with gold and silver. Our chemical and practical readers will at once see the reason of this. It will be sufficient, therefore, simply to state, that the mutual relations of these metals, whether as regards their sources or uses, fully justify this course; for, as we shall eventually observe, mercury is essential in recovering the other metals from their ores; and also in making them, under certain circumstances, adaptable to many applications.

It would be difficult, at the present day, to point out, for certainty, the district or country most noted for its production of gold. Each year, has, for some time past, added one more district at least. In 1880 investigation in the Land of Midian, so often spoken of in the Scriptures, led to the belief that much gold might be found in that country. In 1881 gold was unexpectedly discovered near Buenos Ayres and numerous companies were formed to work gold mines in India. In the East, Japan, China, Siberia, the East Indies, and India generally; Australia, New Zealand, and Tasmania—all afford it in more or less abundance. Africa, and, possibly, Arabia, have been long known as gold-affording or producing countries; but it is most probable that the gold from Arabia has first been imported from Africa. Many parts of continental Europe, and even our own islands, afford gold; the most recent commercial production of which, so far as this island is concerned, has been in Wales and Scotland. Some years ago a gold fever broke out in Sutherlandshire in Scotland, which ended, however, in disappointment and ruin to many who flocked to its so called mines. Ireland formerly produced it in some abundance; but no great amount, even as specimens, has been there discovered of late years. The whole of continental America is more or less productive of gold. At one time Brazil was most noted; but recently, the gold-fields of Columbia, in western North America, and other parts adjacent thereto, have occupied a prominent position in respect to gold-supply. The metal was first discovered in British Columbia in 1856; but no

large amount was afforded for two or three years later. In our American possessions, besides Canada—as Nova Scotia, &c.—gold has been discovered. Perhaps the largest quantity of gold that has been supplied from any country, during the last twenty years, has been from our Australian colony of Victoria, the golden trophy of which, as erected in the London Exhibition of 1862, will be remembered by many of our readers. It was an obelisk seventy feet in height, and represented the bulk of gold produced in the colony from the 1st of October, 1851, to October 1st, 1861; the weight of which was estimated at 26,162,432 ounces troy; and its value at about £105,000,000. The production of gold in Victoria has been going on at a similar rate for the last twenty years.

When gold was first discovered in Victoria the whole of our colonies in Australia were seriously affected. As an instance of whichwe quote the following as descriptive of the result produced in Adelaide, the Capital of South Australia.

"The excitement caused by the gold-finding among the inhabitants of this colony (South Australia) has been intense, nearly the whole of our labouring population having left, and those who have not yet done so, intend leaving as soon as possible. The principal part of our male adult population consisted of about 17,000 from twenty-one to forty-five years of age; and it is computed that out of this number 10,000 have left the colony within the last few months. There were from twelve to fifteen vessel regularly laid on at Port Adelaide for passengers to the Victoria diggings, and from 1,000 to 1,500 souls were leaving the colony weekly. But few females have hitherto left, though they are now beginning to leave. Such a flood of emigration from this place is producing the most disastrous results. The average drain of specie from each of our three local banks exclusive of the Savings' Bank, is just now from £40,000 to £50,000 weekly. Trade is completely stagnated; the stores of the port are filled with wool, copper, tallow, &c., all waiting for shipment. Owing to the scarcity of labour, it is with the utmost difficulty anything can be put on board ship. Seamen are obtaining from £10 to £15 per month for the run to London; and many decline going to England on any terms. Freights are, in consequence, looking up. Should this state of things continue much longer, it will be questionable whether any ship can leave our harbour for England at all. Landed and household property have become depreciated at least 75 per cent. on their former value. Our mining and smelting interests are suffering severely; most of the men from the works of the Patent Copper Company and the Burra mines are leaving for the diggings. Burra shares have fallen from their maximum point of £225 to £50 per share, and will decline still further. Fortunately, out of the 15,000 bales of wool which we annually ship to England, about 12,000 of this season's clip have already gone, leaving only 3,000 bales or so to be shipped; and it will be no easy matter to get the remainder away."

Such is an instance of the insane thirst after gold which characterises civilised humanity, but it is only a type of the same which have occurred in all the newly discovered gold districts of recent years.

Gold is found chiefly native—that is, unalloyed with any other metal—but especially connected with quartz matter, as a rule. It occurs in felspathic and hornblende rocks, in conglomerates, in alluvial deposits and sands of rivers, washed thither from its original vein by the force of a stream, consequent on the denudation of the rocks, in which it earlier rested in veins. It is also found in veins of greenstone, sienitic porphyry, quartz, and selenide of lead; at times associated with silver, iron, and other metals.

From any of the ordinary sources of the metal its extraction is comparatively easy; first, because, with the exception of platinum, gold, of all ordinary metals, has the highest specific gravity; secondly, on account of its colour, by which it is readily recognised; and also because it resists the action of all the acids usually met with, only excepting nitro-hydrochloric acid, or *aqua regia.* It is readily distinguished from copper, brass, or any yellow compound (iron and copper pyrites) of metals by its softness, being easily cut with a knife.

Some amusing instances of error in this respect, however, occasionally present themselves to the practical chemist, arising from unfounded suppositions on the part of persons ignorant of geological and chemical facts. As an instance of this we may relate two cases that came under our notice. One was that of a lady who had discovered some micaceous particles in an alluvial deposit, that, unfortunately for her ideas of prospective riches, proved cleavable mica, fashioned into transparent and almost colourless plates, of small size, but certainly much resembling gold. Essex was the locality of this curious and erroneous discovery; and the Malvern Hills presented a second illustration of the same untoward error. A penknife may always be considered as a test for gold: for if a little mass be readily divisible *without leaving sharp edges* (for the softness of native gold would not permit of that), it may be safely inferred that any specimen so tested has all *primâ facie* evidence of a golden origin—"It is not all gold that glitters."

The external condition of gold, as obtained native, greatly varies. As a rule, it is not found in veins, but in beds, or alluvial deposits, the sand of streams, and in other places, where it has undergone attrition and comminution. The original vein has been broken, and the pieces of gold have been rubbed so continually, as to reduce much of the mass into dust. In fact, the condition of the stream-tin stones, as described at p. 118, is very similar to that of gold, as generally obtained. Being a soft metal its edges are generally smoothed off, especially when found in large masses; but being unacted on by any natural chemical agent, the pieces so removed are not oxidised or dissolved, as would occur with copper, tin, lead, &c., but sunk in the sand, afterwards to be found as gold-dust.

Gold, however, has been discovered in crystals; and, by the crystallised specimens so obtained, the metal ranks in the cubic system of crystallographers. A few very perfect crystals were found some time ago in California, a description of which was given at the time, in a paper read by Mr. Alger, before the Boston Society of Natural History, U.S. "The crystals were distinctly octahedral, the surface being but slightly disfigured by attrition, or the effects of transporting action—a very unusual circumstance, as gold is generally found in minute grains, at a distance from the rocky matrix in which it was primarily imbedded. * * * * Of the larger specimens of those found in California, the most striking examples were three octahedrons, of the sizes exhibited in the annexed cut. Each of these crystals was found in an isolated state. The smallest one (No. 1) is the most perfect, and is so entirely free from any adherent portion of the matrix, to which it must have been attached, as to lead Mr. Alger to a very important conclusion—namely, that this matrix was a much softer material than quartz, in connection with which gold is usually found. He thinks, also, from its slightly worn appearance, that it had been but recently dislodged from its original place of deposit (see Fig. 140, p. 148). This unusually perfect crystal exhibits, as partly shown in the figure, four pretty regular faces on the upper half, and three of its six solid angles are perfectly formed to a point. Two of its faces are sunk or depressed; and in one of them the cavity thus formed is very deep and regular, like an interior triangle, the depression extending not quite to the edges, but so as to leave all round a narrow ridge, or border, the interior sides of which are parallel with the edges themselves. * * * * In the largest (No. 2) of the three crystals, it will be observed that only one-half of the octahedron is formed, its base blending with rough gold, or showing only the commencement of the planes of the lower pyramid. Three of the planes are quite smooth, except along their edges, which are prominently marked by the same projecting border, or ridge, described on the other crystal. The depression, however, arising from whatever cause, is not so great as in the latter. * * * * The two large crystals (Nos. 2 and 3) were obtained from the beautiful collection of Mr. Platt. * * * * The remarkable size of these, and the fact that some other crystals contained portions of oxide of iron, induced a suspicion that the greater part of them were pseudo-morphs of sulphide of iron; but Mr. Alger believes that they were formed under the ordinary circumstances of cystallisation, either in a open space, or while surrounded by the matrix, in such a fluid state as to allow them full freedom to take the form natural to them." For the preceding summary of Mr. Alger's paper, we are indebted to the *Imperial Journal of Art and Science*, in which the writer continues to illustrate, beyond the above quotation, the nature of gold crystals generally, and the cystallographic system to which the metal belongs; concluding by the observation, that "in all these (specimens), the octahedral form is manifest, which may therefore, be assumed to be the form natural to gold when its particles are cooling."

Many fine specimens of native gold may be seen in the British Museum, and in the collection of the School of Mines, Jermyn Street, London, where the geological, mineralogical, and other characteristics of metal and their ores, may be most advantageously studied by all interested in such questions.

We have noticed already, that, as a rule, quartz forms the matrix of gold, as found in veins. Iron, it has also been stated, is occasionally present; indeed, the red mark of the peroxide is frequently noticed in veins containing gold. This metal and iron are thus almost universally distributed—a fact curiously singular, because, throughout all ages of the world's history, their properties, uses, &c., have been considered as so far removed from any relationship except that of both being metals.

Having thus noticed the chief localities of gold-finding, we may turn to a similar inquiry respecting silver and mercury, before entering into an account of the various methods adopted to recover or reduce each of the metals.

Silver having a much greater tendency to unite with chlorine, sulphur, and other non-metallic elements, as well as with several metals, is much more rarely found in a native or uncombined condition than gold. It is, however, widely distributed, and is found mostly in veins, and more rarely in beds; crystalline slate rocks, gneiss, mica slate, hornblende slate, granite, sienite, and porphyry, being its chief geological localities of deposition. It thus occurs in Cornwall, Scotland, &c., in our islands; many parts of Austria; in Normandy and Sweden; the Hartz Mountains, the Tyrol, France, Siberia, &c.; and in various parts of North and South America, as Mexico, Chili, Peru, Nevada, and other places. In its native condition it belongs to the cubic system of crystallography; and has a specific gravity of from about 10 to 11; water = 1·0.

Generally speaking, lead ores contain variable amounts of silver—a fact already noticed in the description of lead, and which will be the subject of further explanation. In some Austrian lead ores, $33\frac{1}{2}$ ounces to the ton have been obtained; but the produce is exceedingly variable and uncertain. In Prussia, silver is chiefly obtained from lead ores: the mines of the Erzebirge are particularly to be noted as silver-producing, and have been long worked. United with selenium and copper, silver is found in the mineral *Eukairite;* which is, consequently, a selenide of the two metals. *Naumannite* is a selenide of silver. *Stromeyerite* is a sulphide of silver and copper, that has been occasionally found. *Argentite*, a valuable silver ore, occurring in Norway, Austria, the Hartz, Spain, Siberia, Mexico, Peru, and, occasionally, in Cornwall, is found in veins; and is the sulphide of the metal, or compound of sulphur and silver. *Sternbergite*, or flexible silver, is a compound of the sulphide of silver and that of iron; and is found in veins with *Pyrargyrite* and *Argentite*. *Stephenite* is a

compound of silver, antimony, and sulphur; and is a valuable silver ore. It occurs in Hungary, Bohemia, Saxony, Mexico, &c. *Proustite*, or *Red Silver*, is a compound of the metal with sulphur and arsenic; and *Pyrargyrite*, another valuable ore, in which silver occurs with sulphur and antimony, is found in veins of crystalline slate and transition rocks, granite, and trachyte, in Bohemia, Saxony, Mexico, &c. *Miargyrite* is a compound of a sulphide of silver and antimony, but is very rare. Combined with mercury, as an amalgam, silver is found in beds containing mercury and cinnabar, in various parts of Europe; and in Chili, in the Arquero mine, whence it has been termed *Arquerite*. *Freieslebenite* is a sulphide of silver and antimony; and *Xanthocone*, one of silver, arsenic, and sulphur. A carbonate of silver exists in *Selbite*. *Kerate*, or *Horn-silver*, is a chloride of the metal, generally rare; but of which a large mass was found, some years ago, at North Dalcoath, in this country. It also occurs in Mexico, Peru, Chili, &c. *Bromite* is a bromide of silver, found with

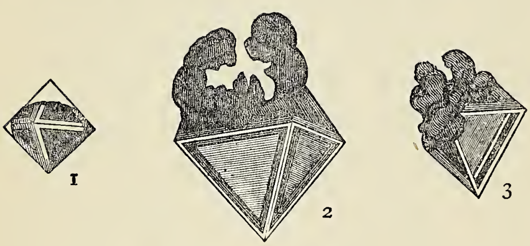

1 2 3

Fig. 140.—Gold Crystals.

Kerate. *Iodite* is an iodide of silver, occurring in Mexico, Chili, and Spain, in serpentine and porphyry.

From the preceding details of most of the known ores of silver, it will be seen how numerous are its combinations, and the variety of physical and chemical aspects it presents in such varied combinations. The localities, however, are generally the same for most of the ores, common or rare; and practically, we may reduce its sources to the lead ores of Europe, and to other ores found in Germany, Spain and Russia, Siberia, Mexico, California, Chili, Peru, and some districts in North America. Generally, it may be remarked, that whilst our sources of gold have greatly increased, those of silver have, comparatively, remained stationary, although its market price has of recent years greatly fallen.

It would seem that, in former times, our own islands were considerably productive of silver. Mr. Barlow observes—"We learn, from some of our early historians, that silver was formerly extracted from mines in various parts of England and Wales. In the reign of Edward I., sixteen hundred pounds weight of silver were obtained, in the course of three years, from a mine in Derbyshire, which had been discovered about the beginning of that reign; and is called a silver mine by the old writers: but it appears to have been only a lead mine that contained silver. The lead mines in Cardiganshire appear to have afforded, at different times, a great quantity of that metal. Sir Hugh Middleton is said to have cleared from them £2,000 per month; and to have been enabled thereby to undertake the great work of bringing the New River from Ware to London. The same mines yielded, in the time of Charles I., eighty ounces of silver in every ton of lead; and part of the king's army was paid in this silver, which was minted at Shrewsbury (according to Sir J. Pettre, in his *Essay on Metal Works*).

"A mint for the coinage of Welsh silver had been previously established at Aberystwith: the indenture was granted to Thomas Bushel, for the coinage of half-crowns, shillings, sixpences, twopences, and pennies; and the moneys were to be stamped with the ostrich feather on both sides. In 1604, nearly 3,000 ounces of the Welsh bullion was minted at one time at the Tower. Webster, in his *History of Metals* published in 1671, makes mention of his own knowledge of two places in Craven, in the West Riding of Yorkshire, where formerly argentiferous lead ore had been procured. One of the places was Brong-hite Moor, in the parish of Slaidburn; the ore held the value of sixty-seven pounds of silver to the ton; the other was at Skelkhornfield, in the parish of Gisburn; it had formerly belonged to a person of the name of Pudsey, who is supposed to have coined it, and there were many shillings in that county which the common people called Pudsey shillings." Other historical accounts point out the fact, that both silver and gold were much more abundantly produced in these islands than is generally supposed to have been the case. Practically, our modern silver production is confined to that obtained from lead ores, as already explained.

In other countries silver-mining is not an accidental consequence of that of lead, but becomes a special occupation; and the mines of Mexico and Chili and Peru have long been known for their productiveness, and the peculiar circumstances of difficulty that attend getting the ore. In fact, in those countries life and avarice are in constant contest for existence, the one generally terminating the other. The inaccessibility of the mines to all ordinary modes of carriage, and the distance at which they are placed from all sources of the ordinary means of existence, render silver-mining and production in such countries a disgrace to the civilised world. It is to be hoped that, in the course of time, a further application of mechanical appliances will reduce the labour now thrown on humanity. When we read of men climbing steeps, loaded with 200 pounds, which, without a load, are barely accessible to ordinary human beings, and this for a mere trifle of wages; whilst their employers, or rather owners (for they are little better than slaves), are amongst the "honoured" of the world, in this and other European countries—are esteemed as philan-

thropists, patrons of science, art, &c., &c.—we can only come to the conclusion that, in certain respects, morality, in its strict and legitimate sense, is, at present, a delusion and snare, a garment for wolves literally in sheep's clothing.

We omit, for the present, all description of the preparation of the ores of metals with which we are now dealing; but state, generally, that those of silver are, as a rule, reduced in the country in which they are found, and that the metal is exported in bars, ingots, &c., to other countries in the usual course of trade or exchange.

Some years ago, Mr. Darwin published an account of a visit he made to a Chilian mine; and the hardships of the *apires*, or men who carry up the ore from the mine, are graphically represented. "According to the general regulation, the apire is not allowed to halt for breath, except the mine is 600 feet deep. [They ascend and descend by a species of ladders, in a similar way to that already described, in respect to the access to our own mines in Cornwall and Devon.] The average load is considered as rather more than 200 pounds; and I have been assured that one of 300 pounds, by way of trial, has been brought up from the deepest mine. At this time, the apires were bringing up the usual load twelve times in the day; that is, 2,400 pounds, from a depth of eighty yards; and they were employed in the interval, in breaking and picking ore. These men, excepting from accidents, are healthy, and appear cheerful. Their bodies are not very muscular. They rarely eat meat once a week, and never oftener, and then only the hard dry beef, or *charqui* (lately imported under that name, and as 'jerked beef,' into this country.) Although with a knowledge that the labour is voluntary, it was, nevertheless, quite revolting to see the state in which they reached the mouth of the mine; their bodies bent forward, leaning with their arms on the steps; their legs bowed: the muscles quivering; the perspiration streaming from their faces, over their breasts; their nostrils distended; the corners of the mouth forcibly drawn back, and the expulsion of their breath most laborious: each time, they, from habit, utter an articulate cry of 'ay-ay!' which ends in a sound rising deep from the chest, but shrill, like the note of a fife. After staggering to the pile of ore, they emptied the carpacho; in two or three seconds, recovering their breath, they wiped the sweat from their brows, and, apparently quite fresh, descended the mine again at a quick pace." Mr. Darwin adds, that it appears to him a wonderful instance of the amount of labour which habit (for it can be nothing else) will enable a man to endure. And to this we add, that such a degradation of man, made in the image of his Maker, is not confined to Chili, but may equally be seen in many of our mining districts of this country. Sir Francis Head gives a similar account to that rendered by Mr. Darwin, of the hardships which the Chilian miners undergo. He remarks, after an ascent from one of the mines:—"The English miner who was with me, was one of the strongest men of all the Cornish party; yet he was scarcely able to walk with it [the load the apire had brought up the ladder from the mine]; and two of our party who attempted to support it, were altogether unable, and exclaimed that 'it would break their backs.' This load, which we tried, was one of specimens which I had paid the apire to bring up for me, and which weighed more than usual, but not much; and he had carried it with me, and was above me during the whole of the ascent," although Sir Francis found the fatigue of climbing the notched sticks (or ladder) was so great that each of his party (unloaded) was almost exhausted.

Last, in respect to its localities and ores, we have to deal with mercury, or quicksilver, the only metal fluid at ordinary temperatures, and whose uses are so important, and extensively ramified. It may, indeed, be considered in part as the solvent of metals, as water is of most salts; for it combines with many metallic bodies, rendering them soft or fluid at ordinary temperatures, and yet leaves them, entirely unaltered in their chemical qualities, by the agency of heat, the physical condition alone being affected by its action. In the arts and medicine it is largely employed, and hence ranks amongst the most important of the metals.

Mercury is met with in a native state, in crevices of rocks containing cinnabar, especially in Spain; also in Carniola, Bohemia, the Tyrol, Carinthia, the Hartz, China, Peru, and in other parts of America. Almaden, in the sub-province of Ciudad Real, Spain, and fifty miles south-west of that city, is situated on the northern slopes of the Sierra Morena range, and is famous for its mines of quicksilver, that have been worked at least since the time of the Romans. The mines belong to the government, but are generally leased out; and they have frequently become one of the principal securities for public loans. Their importance may be imagined; for, some years ago, falling into the hands of an eminent financial firm, the monopoly that resulted caused a great increase in the price of the metal. They are entered by vertical shafts, and are at present opened to a depth somewhat above 1,000 feet. Here the metal exists in a native and combined state—that of *Cinnabar*. The latter is a sulphide, or combination of mercury and sulphur. Its general colour is red; and a pure variety is well known, from its beautiful colour, as vermillion. Cinnabar is met with in Spain (as already stated), Bohemia, Saxony, the Hartz and Ural Mountains; Syria, China, Japan; Mexico, Peru, and other parts of America. It is the most important and abundant ore of mercury; and, indeed, on it and the native metal our sources of quicksilver depend. It occurs in beds and veins. In Idria, in the south of Austria, important mines of cinnabar are situated. They are arrived at by a descent of about 800 steps; and "the mining operations are carried on principally in galleries, the friable nature of the rock seldom admitting of large chambers. The cinnabar exists in strata of from two to six inches in thickness, and of a variety of colours, from dark to light red, the quicksilver (metallic) being sometimes mixed

with it, and at times occurring in the intervening strata of earth and stone." In some places the metal is more abundant, and is there the chief object of search in these mines. It is found in particles of extreme minuteness, from a size just large enough to be distinguished by its metallic appearance, to globules of the size of a pin's head. At lower parts of the mine than those just referred to, the globules become larger—very likely from filtration, through its great specific gravity, to lower levels, where a quantity will naturally collect together, and coalesce. Mercury is found under other circumstances, but not such as to be important in a commercial point of view.

Before entering into a description of the various methods adopted in practice to obtain gold, silver, and mercury in sufficient abundance for the purpose of commerce, it may be desirable to make a few remarks on their physical and chemical qualities; for on these the various modes of reduction or preparation entirely depend, and, indeed, distinguish them, in the latter respect, from iron, copper, tin, lead, and zinc; all of which, having powerful affinities with other non-metallic and metallic elements, present several difficulties in their reduction.

The external qualities of all are familiar, from their common uses in daily life. Gold has a specific gravity varying from 19·25 to 19·5; silver, one of about 10·5 on an average; and mercury, one of 13·5 at ordinary temperatures, becoming about 14·0 when frozen. Gold is especially distinguished by its beautiful yellow colour, softness, great ductility and malleability. Silver is the whitest of our ordinary metals, and is scarcely inferior to any other in its ductility, &c. Mercury has a much bluer colour than silver; is fluid at ordinary temperatures, becoming solid at a degree of cold equal to 40° below zero, or 72° below freezing-point of water, in the scale of Fahrenheit, at which temperature it may be beaten out into leaves. At a temperature of 660°, or thereabouts, it becomes vaporous, a quality on which many of its most important uses depend, especially that of extracting silver and gold from their ores. Each of these metals, when pure, possesses a fine polish. Gold has one that, practically, cannot be tarnished by ordinary means. Silver, although unattacked by air and moisture, is readily acted on by sulphur; hence it tarnishes in rooms where gas, coal fires, smell of drains, or any other cause of sulphur-evolution is operating.

The tendency of these metals to form combinations with non-metallic bodies, is generally slight; and, in most cases, heat, and sometimes even friction, cause their reduction again to the metallic state. Gold and silver cannot be oxidised by any heat short of that of the disruptive discharge of the voltaic battery. Both may be kept for any length of time in a fused condition without loss of weight; although silver, mechanically, absorbs oxygen, which it parts with on cooling and becoming solid. Chlorine unites with each of these metals, forming chlorides—all of great use in various arts; those of mercury, but especially calomel, being of extensive use in medicine. Their iodides have hitherto been chiefly confined in use to the art of photography; whilst their cyanides are of still more extensive employment in electro-metallurgical processes, for electro-gilding, plating, &c.

Gold is insoluble, except in nitro-hydrochloric acid, or *aqua regia*, by the agency of which it affords a protochloride and a terchloride. Silver is chiefly soluble in nitric acid; its nitrate has extensive uses in photography, and as lunar caustic in medicine. Other salts of these metals are formed by union with acids; these are of comparatively little general interest.

All these metals form fulminating compounds; that is, such are decomposed by heat or friction, attended with a noisy explosion. The most important is the fulminate of mercury, or, as it is more usually called, *fulminating* mercury, which is largely used in making percussion-caps for detonating guns.

It has been recently discovered that the ocean contains an immense amount of silver in a soluble state—a fact first indicated by its deposition on the copper sheathing of the bottom of a vessel. The fact is strange; for, whilst chlorine, in any form, precipitates silver as an insoluble chloride, yet that element is, of course, one of the most important in the saline matter of the ocean, as a chloride of sodium (or common salt), and other soluble chlorides. Ammonia, however, dissolves the chloride of silver; and, possibly, its presence in sea-water, or the yet undiscovered fact in our laboratories, that chloride of silver can be partly soluble, may be considered to account for the constant presence of silver in the sea. It must be remembered, also, that at least four metals have, until recently, quite escaped the notice of experimental chemists—viz., cæsium, rubidium, thallium, and indium—that have all been discovered by infinitely more delicate means than the most refined ordinary analytical processes: for spectrum analysis alone placed them before us in the category of existing metals; and so minute was the proportion in which thallium existed in the first sources available, that many tons of water had to be evaporated before a few grains of this really "precious" metal were obtained.

In a chemical point of view—that is, in respect to the more abstract principles of chemistry than we have yet noticed—there are many other circumstances of interest: for example, their combining proportion, or equivalent, in each case is high, varying from about 100 in mercury, 108·0 in silver, to 197·0 in gold; hydrogen being the standard or unity = 1·00 of the scale. Their combinations are generally denoted by great weakness of attraction or chemical affinity for all the ordinary agents of use for such purposes in the laboratory; but especially in respect to oxygen. As we shall presently more fully notice, they are all readily reducible from ordinary solutions to the metallic condition; and each is characterised by high specific gravity. Geologically, we have seen them to be, in a certain degree, related; and, physically, the qualities of gold and silver much resemble each other. Of course no comparison can be made in

the latter respect between these two metals and mercury, because of the fluidity of the latter. Another fact connected with their physical relations is, in respect to heat, that they are all good conductors ; the specific heat of each is nearly expressed by the same number ; and the points of fusion of gold and silver are not far apart. Taking, therefore, all the points of connection subsisting between them—geological, topographical, chemical, physical, and the relation to heat ; to which we may add those of an electrical character—the study of these metals, apart from their commercial and general uses, is one of great interest.

We may briefly here point out how they are separately distinguished by the chemist, apart from the operation of cupellation, that will, with assaying, &c., demand extended notice.

To a practical chemist, any advice or instruction in reference to the detection of gold, would seem ludicrous ; for, as already pointed out, it is all but impossible to mistake its presence for any other metal or compound. There are really only two chances for an unpractical person to mistake it for other metallic substances—to wit, brass and the sulphide of iron, or iron pyrites. But to distinguish these from gold is very easily done. If strong nitric acid be poured on to real gold, there will be no more action resulting than if cold water had been used. But, in the case of brass, or any alloys of copper imitating gold (and this has been fraudulently effected), the result is very different. Copious and offensive fumes of nitrous acid, are given off. They are of a red appearance, and are easily judged of by those ignorant of chemistry, if the acid be poured on iron, copper, zinc, mercury, silver, nickel, &c. ; in all of which cases the peculiar red fumes are given off.

Again, if a piece of gold be rubbed on a hard stone, as a flint, or, preferably, bloodstone, it leaves a yellow mark, owing to the impression of its particles on the surface of the stone. If strong or weak nitric acid be dropped on this, no change will appear. But if the metal be not gold, or if a very poor alloy of the metal caused the mark, then nitric acid will have a solvent power, and remove it. There are certain exceptions to this, recognisable at once by the practical chemist, but which can never ordinarily occur.

It has already been pointed out that gold is only susceptible of solution in nitro-hydrochloric acid, otherwise termed *aqua regia*. This, as a rule, suffices to distinguish it from any other simple or compound metal (that is, an alloy). But, occasionally, substances are met with that present an appearance so like gold-dust, in the form of yellow pieces of mica, that all but the experienced might be deceived. Instances of this have been already adduced at p. 146, *ante*. A penknife will generally decide such a question, for it will not be able to penetrate the mica *across* the plate, however small, without splitting it into pieces ; but, laterally, it will divide into plates. By aid of the blowpipe, these micaceous particles may be further detected, for they will fly into pieces. They are also insoluble in any of the mineral acids, and equally so in *aqua regia*, already alluded to. All ores of gold (simply because gold is always found in the metallic state) are soluble in nitro-hydrochloric acid ; that is, the metal is thus dissevered or separated from quartz and other extraneous matters. In fact, there is, practically, no reduction of gold from its sources, unless they have been acted on by some of the chemical agents of the laboratory.

If mercury be well stirred up, and gently heated with any sand or other substance supposed to contain gold, the latter metal is readily separated by heating the amalgam thus formed to a temperature above 700°, when the mercury will evaporate, and leave the gold as a solid residue. One of the methods of obtaining gold from poor "ores," depends on this fact.

If, however, any supposed source of gold—say as the sand of a river—be heated in nitro-hydrochloric acid—say of one part of nitric to two or three of hydrochloric acid—then the gold obtained in a soluble form may be easily recognised as follows :—

If the protosulphate of iron in solution be added to the filtered solution, as above effected, gold, if present, will be precipitated in the metallic state as a brown powder. An excess of hydrochloric acid should be present ; and this would be insured by using the proportions of the two acids for solution just recommended. The amount of gold present may be readily found by filtering the liquid ; retaining the precipitate on a weighed filter ; washing it carefully; and then igniting the filter and precipitate. On weighing, the exact amount of gold present will be found by deducting the weight of the ashes of the filter, which is easily ascertained by burning one of similar weight and size, and weighing the ashes so produced (see *ante*, p. 56, in respect to the analysis of iron ores).

Generally, the tests for gold are as follows ; that is, when in solution :—

Hydrosulphuric acid (sulphuretted hydrogen) passed through the solution, affords a black precipitate of the sulphide, insoluble in acids ; hydrosulphate of ammonia produces the same, but the precipitate is soluble in excess of the precipitant. Caustic potass gives a yellow precipitate of the peroxide in concentrated solutions ; and by a strong liquid ammonia a fulminating aurate of ammonia is thrown down. Chloride of tin gives, with chloride of gold, a fine purple precipitate, already referred to as the *Purple of Cassius ;* and the protosulphate of iron, by deoxidation, as just stated, precipitates finely-divided gold as a brown powder, which shows its metallic character on being rubbed by a hard and polished substance.

If precipitated with some other metals by hydrosulphuric acid, as a sulphide, gold is separated from bismuth, copper, cadmium, and lead, by hydrosulphate of ammonia, in which the sulphide of gold is soluble, while the other sulphides are not. Ammonia and its hydrosulphate should be together in excess for this purpose, and time should be given to allow the solvent action to take place, air being, at the same time, excluded from access to the solution.

The latter being filtered, the gold may be precipitated by means already suggested, with the addition of hydrochloric acid.

Occasionally gold is associated with platinum, and other metals which we shall subsequently classify with it in our future pages. It will be there seen that platinum is precipitable as a double chloride with ammonium.

The separation of gold and silver is effected by a method that will require separate and extended notice, together with that of cupellation; and, for the present, we shall omit mention of either.

Silver is readily detected, in most cases, on account of its affording, from its solution in nitric acid, an insoluble precipitate of chloride of silver, on the addition of hydrochloric acid, or any soluble chloride. The chloride of silver may be distinguished from that of lead by its insolubility in water, in which chloride of lead is sufficiently soluble to be removed by long, but tedious washings; but still more so by the fact, that liquid ammonia dissolves chloride of silver, leaving the chloride of lead untouched. If silver be in excess of lead, no difficulty can occur in its separation; but when the silver is in very small proportions, an inexperienced hand will find considerable trouble in separately estimating the quantities of the two metals present. As in the case of gold, the operation of cupellation will be subsequently considered. If silver is supposed to be present in a solution, it may frequently be precipitated, in the metallic condition, on a slip of clean copper, when its

Fig. 141.—Gold-washing in Brazil.

white appearance will sufficiently indicate its presence; but this method is by no means readily or accurately available for quantitative analysis.

Under all ordinary circumstances mercury is readily recognised. As an oxide it parts with its oxygen by distillation, the metal being afforded in globules by condensation; whilst the oxygen passes off in the gaseous form, and may be readily recognised by the usual tests.

Fig. 142.—The Cerro de Pasco Mines, Peru.

As a sulphide, the addition of iron-filings, and subsequent distillation, affords the metal as globules; whilst the sulphur previously combined with it becomes united with the iron, forming its sulphide. In solution, mercury affords, with sulphuretted hydrogen, a white, yellow, orange to black sulphide, according to the quantity of the solution of sulphuretted hydrogen added. Iodide of potassium, of a weak solution, produces first a yellow, subsequently a red precipitate, the latter being completely dissolved by excess of the alkaline iodide. Hydrosulphate of ammonia has the same effect as hydrosulphuric acid; caustic potass gives a yellow hydrate, insoluble in excess; whilst ammonia affords a white precipitate, also insoluble in excess. Protochloride of tin, in excess, precipitates metallic mercury. A slip of clean copper, in mercury solutions, precipitates also metallic mercury. In testing for mercury to be reduced to the metallic form, all excess of nitric acid is to be avoided; and the presence of this may be destroyed by the addition of hydrochloric acid and heat, both of which should be effected before the addition of the chloride of tin as a reducing agent.

The separation of mercury from metallic combinations is not always easily effected, for many reasons; but there are certain methods usually attended with success. If, for example, any manufactured object of gold or silver be saturated with mercury, the precious metal may easily be separated by heating it, when the mercury will fly off; but the form of the object is generally destroyed. A curious result of this kind came within our notice. Having placed a gold signet-ring on a laboratory table, on which metallic mercury had been left, and heating the ring in the flame of a spirit-lamp, it suddenly became red-hot, and all the rim instantly melted—of course destroying the article.

But the usual method of extracting small quantities of gold and silver from ores, is that of amalgamation, the mercury being afterwards distilled off. Similarly, an amalgam of gold was at one time largely used for gilding buttons, and other small objects, by the process called "water-gilding." The surface of the article was thereby coated with the amalgam, and then put into an oven, the heat of which drove off the mercury. This unhealthy process has now been mostly replaced by electro-gilding.

It may here be remarked, that this metal, even at ordinary temperatures, seems vaporisable; hence its prejudicial effects on the health of all who work with it. The men occupied in procuring it from the mine, looking-glass silverers, and others, all suffer seriously from this cause; salivation, and subsequent serious consequences, arising. Indeed, with the exception of making white lead, there are few branches of metal manufactures so dangerously unhealthy as those in which mercury is employed.

Having thus described the chief chemical and physical relations of these metals, we pass on to consider some points in the preparation, reduction, &c., of the ores, and other matters connected incidentally therewith.

At a previous page, we have named most of the

leading sources of gold at the present day (see *ante*, p. 145), and some of the chief circumstances attending its condition. The latter point has always determined the character of operations in gold mining districts, respecting the collection and preparation of gold for commercial purposes. And here it may be remarked, that the term *mining* can hardly, with strict propriety, be applied to the search for gold, as now pursued in the majority of gold-producing districts; at least, not in the sense in which we use it in reference to coal, iron, copper, tin, and lead mines; because gold is usually found in beds of streams, rather than in a matrix fixed in rock or strata, as is usual with the baser metals. Equally, the term *reduction* can scarcely, with propriety, be applied to gold preparation; for, as it is almost always found in a pure condition—that is, free from chemical union with any other bodies, and only attached to them mechanically—its preparation necessarily becomes one of a mechanical rather than of a chemical character.

It hence follows, that both the search for gold, and its separation from adherent matter, will be influenced by the circumstances in which it is found; and frequently, in old gold districts, by the custom of the country. In all cases, however, the finding of gold may be reduced to three kinds—that of getting nuggets, or large masses of gold, and washing sands for its dust; that of really mining, or the removal of gold from veins and rocks; and, lastly, the method of amalgamating, by which poor "mines," or beds, are made to yield up their treasures, that would, otherwise than by the solvent action of mercury, be irrecoverable.

The following remarks, by Professor Ansted, will afford a useful introduction to the more precise details that will be afterwards given—more especially as he describes what he has personally observed and judged of with the eye of a long-experienced practical geologist.

"Gold-washings are, at present, carried on chiefly in Siberia, California, British Columbia, and Australia: the three latter countries yield by far the largest quantity; but the work in the former is by far the most systematic, and far less costly, so that poorer sands are exposed to the various mechanical operations. The matrix, or earth in which the gold occurs, varies in different countries; but is usually confined to one or two distinct beds of gravel, often of considerable geological age, compared with the surface soil, and spread over a wide tract. The gold, originally contained in veinstone of some kind (often quartz), or disseminated through rocks in a native state, has been washed out of these materials by long exposure, and the abrasion of one particle against another. The gold, being the heavier substance, has been left behind, when, from the action of the water, the fragments of rock have been washed away; and thus it chiefly abounds in hollows or other receptacles, where it was not exposed so much to aqueous action, and, finally, became buried."

In the preceding cut, Fig. 141, is given an illustration of gold-washing under favourable circumstances of abundance of water, a circumstance, as already stated, of by no means constant occurrence.

The aspects of gold and silver mining countries are generally uninviting. The cuts on pages 153 and 157, for which we are indebted to *Engineering*, will give an idea of the silver mines of Cerro de Pasco, in Peru, which, with those of Potosi, are the richest in that country.

Of these mines we shall have to speak more fully hereafter when dealing with silver mining.

It may be here remarked, in reference to the circumstances of gold just mentioned, that, in most gold countries, the rivers are, in hot weather, but little streams, often subsiding into pools; whilst in the winter, or rainy season, they become fierce torrents of enormous width, and rushing with impetuous force to the sea. This is especially the case in Australia, where, in summer-time, most of the leading rivers become completely exhausted, leaving, here and there, stagnant pools, that even themselves get dried up into stiff mud by the heat of the summer's sun—so much so, indeed, that all attempts at gold-washing have to be abandoned for want of water; to be resumed after the floods of the wet season have passed away. On a diminished scale, the same may be observed in respect to certain of the rivers in this country, especially those of small size in Scotland. There, during the summer months, those streams, frequently in rocky districts, are little better than rills; but, as the snow melts on the hills, a torrent is suddenly produced, that carries rocks, stones, trees, and everything before it. But, resuming our quotation—

"In Siberia there are but few localities where the gold-washings are largely carried on; and, in each of these, the metal is disseminated in a quartzy sand, or gravel, containing much oxide of iron. It is not confined to the valleys, but extends even to the hill-tops, and escarped sides of the mountains, proving that the process of accumulation has been a long one, and commenced when the present mountain chains (in that country) were entirely below the surface of the water. In Brazil, as in Siberia, where the observations on gold-mining have been more carefully made than in California and Australia, the gold lies in a stratum of pebbles and gravel, immediately incumbent on the solid rock; and the excavations of the washers in this gravel are often from fifty to one hundred feet wide, and eighteen to twenty feet deep. The author [Ansted] has seen larger and deeper excavations than these in the mining districts of Eastern Virginia (U. S.), where, also, much gold has been obtained. The African gold is entirely got from the beds of rivers; as the Gold Coast in Abyssinia, and on the Mozambique coast: and the same may be said of Asia and the Asiatic Islands."

From the preceding facts, it is evident that no exact data can be given on which we could state certainly that gold might be found; but, by geological analogy, its probability may frequently be averred. Thus, up to about the year 1840, it was not ascertained that abundance

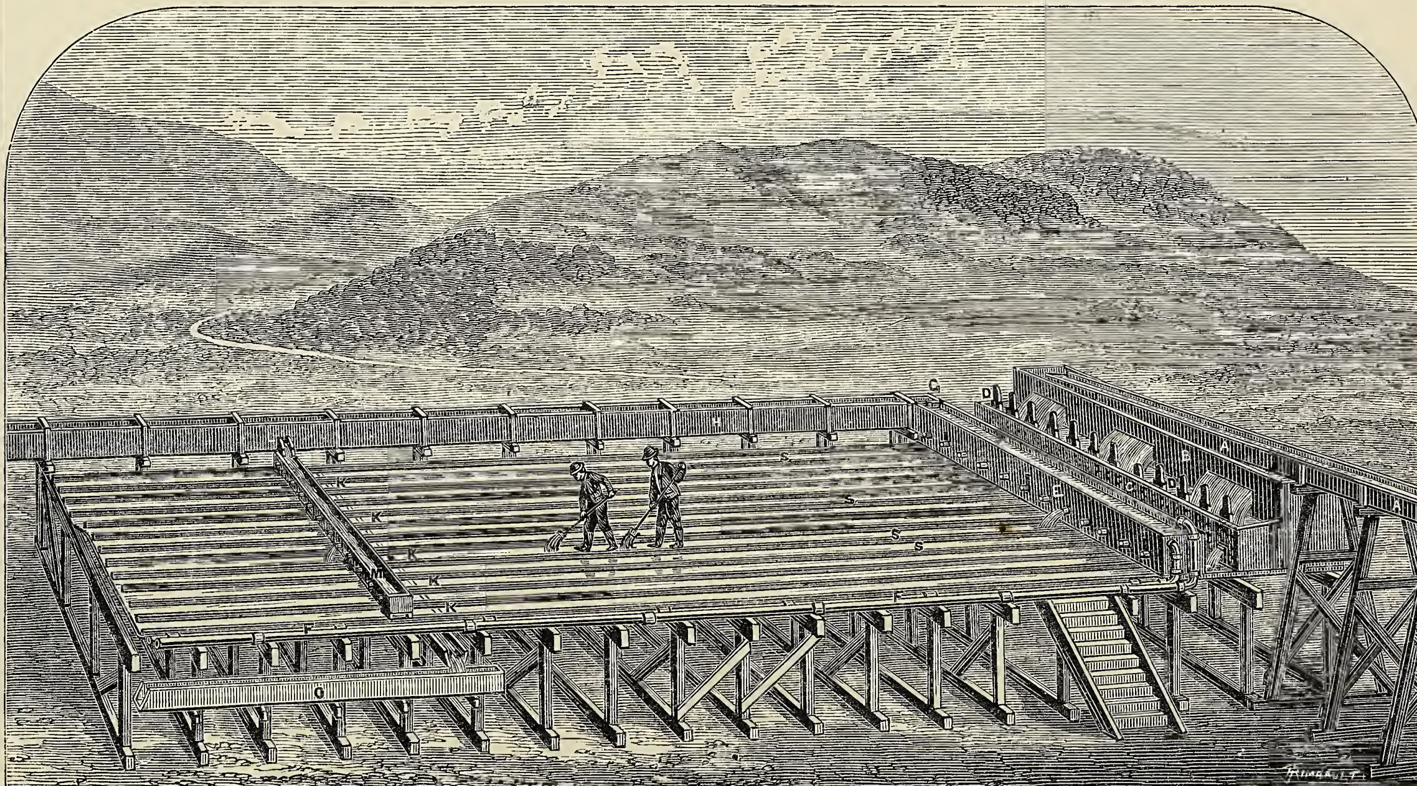
of gold existed in Australia, although some small fragmentary masses had been picked up; just as may constantly occur in Cornwall, some parts of Scotland, as the Isle of Arran, and Ireland, in our own islands. But, by comparing ranges of rocks, and their mineralogical constitutents, newly discovered, with those already known, it is possible to predict the existence of gold with comparative certainty. A remarkable instance of this occurred in reference to the Australian fields. A communication was made by the Rev. W. B. Clarke, resident near Sydney, in 1841, to the Geological Society of London, to the effect that he had discovered gold in the basin of the Macquarie River; and expressing his opinion that gold, copper, and lead existed in quartz and schist rocks of adjacent mountain ranges. Reasoning on the data thus supplied, and comparing the facts with those he had become personally acquainted with in the Siberian rocks producing gold, that eminent geographer and geologist, the late Sir Roderick Impey Murchison, came to the conclusion that the analogous ranges of Australia must equally be so gold-producing; and so convinced was he of the truth of such a speculation, that he urged on the Geological Society of Cornwall, in 1845, to send out a party of experienced miners to explore the country. Eventually, Sir Roderick's views were amply justified by the result, and the inductive character of modern science was vindicated triumphantly; but still, it is a most singular fact, and one illustrating the then want of faith generally prevalent in respect to geological theories, that despite the cupidity for riches (especially gold) that characterises all civilised countries, no effective steps were taken for five years to ascertain the truth of the suggestions that had been made, and which were constantly being verified, in the interval, by frequent discoveries of various-sized masses of gold.

Thus, whilst occasional proofs became known that *some* gold could be found in our Australian possessions, it was not until the beginning of 1851 that Mr. Hargreaves succeeded in demonstrating the enormous amount of the precious metal that really existed in Australia. In February of that year, Mr. Hargreaves left Sydney for Bathurst, intending to prosecute a systematic search for gold, for which he had been prepared by a previous residence in California. By May of that year he had succeeded in finding numerous deposits; and, on the 8th of that month, Mr. Hargreaves publicly explained what he had done and discovered. The result is now a matter of history. In the course of a few weeks the "diggings" were generally entered on by all classes of persons; and that portion of Australia, so far as its white inhabitants were concerned, went literally gold-mad. An instance of this has already been given at page 146 *ante*, describing the wholesale exodus which took place from South Australia to Victoria when the gold-diggings or fields of the latter were discovered.

When once the presence of gold, generally diffused in a country, has been ascertained, it does not require much knowledge of science to discover it, if examination be made in the beds of existing or extinct streams; simply because, uncombined chemically with any other substance, its external qualities of colour, sectility, &c., can be easily recognised. Hence any man who has once cut a sovereign with a penknife (see *ante*, p. 146) may readily become a successful gold-finder, if he provide himself with an iron pan, a board, and a supply of water. Thus, if a basinful of the gravel, sand, &c., be collected, all the stones picked out and examined as they are brought up to the surface by shaking the pan, and, after their removal, the sand be washed out with a gentle stream of water, the basin being held at an angle, the gold, having eight times the specific gravity of the quartz sand, will be left in the corner of the basin, whilst the earthy particles are gradually washed out by the stream of water. The bottom of the basin will then present the gold, if in masses large enough to be distinguished by the naked eye; and, of course, it may readily be removed, and further washed until it is quite cleared of all earthy impurity.

But it frequently happens that the gold, although present, may not be in pieces sufficiently large to be so discovered by the naked eye, and amalgamation must be had recourse to. The same plan of washing is adopted as just explained; and when all the lighter particles are removed, those that lie at the bottom of the pan are mixed with some pure quicksilver, and the mass is constantly stirred together for some time. The mercury will dissolve all the gold present, and abundant washing will leave nothing but an amalgam in the pan. This should then be strained, poured off, and heated until all the mercury is expelled, when the gold will be discovered in the metallic state, and almost, if not quite, pure. From the simplicity of the entire process, so far as rough-and-ready means of examination are concerned, it follows that any one, without the slightest knowledge of chemistry, may work at gold-seeking with a certainty of success, if even a minute quantity of gold be present in the gravel or sand.

In the early days of gold-finding, in various parts of Australia, this rough mode was universal; and it has not been without its subsequent advantages; for as the first diggers never troubled themselves to hunt for gold by careful amalgamation, but simply by washing for particles of the precious metal that the eye could detect, they left great riches behind them for recovery by those who had more science, patience, means, and method. Speaking of visitors to the gold-ground—"When they arrive on the diggings, instead of, as most of them expect to see, a busy scene, with men in fancy costume, perhaps digging up ground as if it were a garden, or picking up large nuggets of gold as chestnuts under a tree, they see nothing on every side but little hills, gulleys or valleys, for the most part abandoned, completely cut up, and one unshapely mass of upturned earth. They go down for a nearer inspection, and find that the upturned earth is the dirt thrown out of deep



The Woodworth Sluices for treating Silver-tailings at Dayton, Nevada, U.S.A.

holes, varying, according to the locality, from ten to thirty or thirty-five feet deep. They see men up to their middles in water, perhaps bespattered with clay and dirt, picking and working as hard as any railway navvy in England."

Of course, the first diggers *did* expect to pick up gold in nuggets as big as chestnuts; and because this was not universally effected, hundreds returned, disappointed by their want of success, and disgusted at the useless labour, self-denial, and various discomforts they had to undergo. Many remained in the desert, victims of avarice and disappointment—committed to the very holes in which both their bodies and hopes were buried.

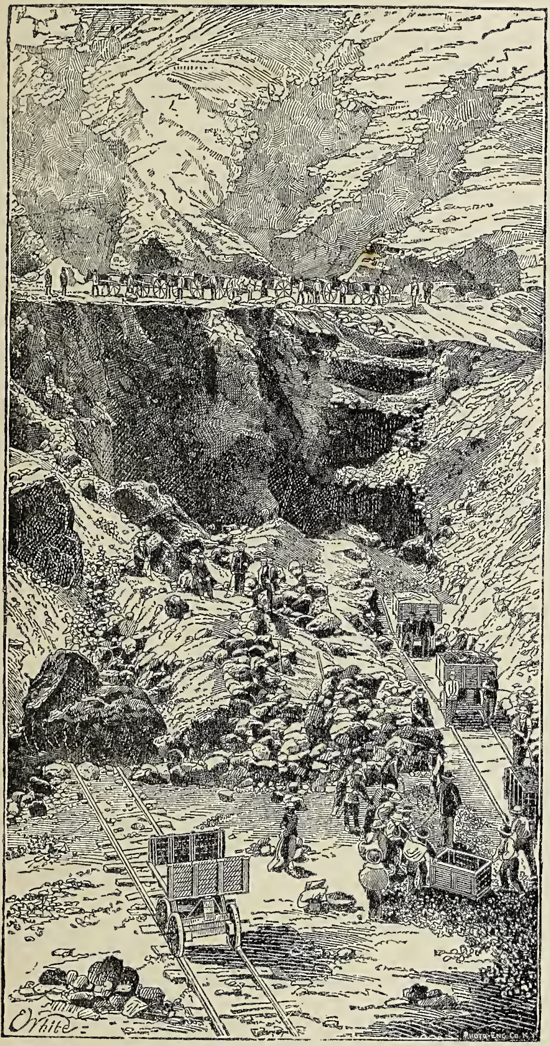


Fig. 143.—Mining in open cut, working two benches at the Cerro de Pasco Silver Mines.

Gradually more systematic arrangements were made. Parties and companies were formed for joint labour, and also personal defence; for the finding of gold bred as hardened a race of desperadoes as ever disgraced humanity. Instead of confining attention to pieces of gold lying loose in the sand, search was made for auriferous quartz, of which we shall speak more fully presently. The basin or pan was replaced by the cradle—the earliest form of gold-washing machine used in Australia. It was, indeed, of a primitive form. "The cradle in general use is made of wood, and in size and form resembles a child's cradle. It is about six feet long; stands on rockers; and into the head is fitted a box, the bottom of which is a grating or sieve of coarse wire-work, or sheet-iron pierced full of holes half an inch in diameter. Three bars or ridges, about three-eighths of an inch in height, extend across the inside of the bottom of the cradle; one beneath the centre of the sieve, one near the extreme end, and the other midway between the two. An upright bar of wood is fastened to the middle of one of the sides of the cradle. By means of this bar the rocker keeps violently rocking the cradle with one hand, and with the other pouring water on the soil which has been thrown on the sieve; and as the gold and sand are separated from the stone, and washed down, the current carries the bulk of the sand over the bars, while the gold, mixed with a pasty soil, is intercepted, the lower bar arresting any that, by an awkward shake, gets over the upper ones. When in use, the cradle is placed in a slanting position, with the sieve-end higher than the other. Twice, or oftener, in the day the paste is cleared out from the bottom of the cradle, and either dried in the sun, and the sand blown away, or washed in a milk-dish—the grains of gold, by their superior specific gravity, remaining at the bottom."

Improvements were gradually introduced, owing to the influx of miners of all nations; but especially from California, where news of the gold discovery soon arrived, with all its fabulous abundance. The methods previously described were, of course, of the most wasteful character, and proceeded on no scientific basis; indeed, as already intimated, a great quantity of the finer particles of gold were washed away, and, for the time, lost.

Amalgamation, to recover them, and generally to increase the production of gold from the soil, was next introduced; and the process was carried on, by aid of a machine, in the following manner:—"The machine is about six feet long by eighteen inches broad, and has a plate of iron throughout the whole length, with three-eighth of an inch holes bored or punched in it, about one inch from each other. Below this is the rifle-box, also extending throughout the whole length, with eight or nine partitions or rifles, into each of which a pound and a-half or two pounds of quicksilver are placed. The earth,

stones, &c., are thrown on the iron plate, through which the earth passes with the gold into the rifles below, while the stones go off at the lower end. When the machine is in motion, the quicksilver traverses through the dirt, and amalgamates with the gold; while the dirt and pebbles are washed out of the machine by the force of the water, leaving the quicksilver behind containing the gold. At night the whole of the amalgam is taken out, washed clear of the earth, &c., and then strained through a leather bag, by which it is reduced to a thick paste, from which the quicksilver is separated by distillation in a retort, leaving the gold in one solid piece. The rocker must be worked regularly and steadily, not even stopping for an instant, unless when cleaning the box. To do it justice, eight men are require for one machine; two in the pit digging, two bringing the dirt in wheelbarrows, one man rocking, one pumping, one supplying the machine, and one taking or throwing away the stones as they come out."

Of recent years all that mechanical, engineering and chemistry could suggest has been adopted to get the smallest quantity of gold from the sands and matrix. But it would take up too much of our space to even enumerate the various inventions that have been brought out. Those who wish to inquire more fully into the details of this subject may consult Dr. Percy's work on Metallurgy, and the columns of *Engineering*, where abundant illustration and description of all the most recent methods will be found.

We now turn attention to what may be more properly considered gold-mining, or the removal of the ore from its matrix, and the rock in which it occurs; and the usual methods adopted in separating the gold found in such conditions.

It will have been noticed that, as a rule, the matrix of gold is quartz, respecting which a short description may be desirable; as also of the "rocks," granite, clay slate, mica slate, &c., in which gold is naturally or accidently present; because all these tend to form the sand that afterwards accompanies the gold in its comminuted state in the beds of the rivers; whilst the rocks themselves first contained it in the solid or vein-like state.

Quartz, when perfectly pure, is simply silicic acid; that is, silicon combined with oxygen. In an impure form we have it as flint in the chalk formations of Kent, and other parts of our islands; in an enormous quantity in the sand of our sea-shores; in all kinds of clay, which may properly be considered as a silicate of alumina; in our heaps of sand, beds of rivers, pebbles, &c.

In each of the instances named, except pure quartz, silicic acid is generally mixed with iron; hence the red appearance of sand, gravel, &c. The purest form of silex, or silicic acid, is, perhaps, that of rock-crystal. Quartz receives various names, according to its colour: amethyst, one of our more common precious stones, is a species of quartz; and the term, although formerly restricted to the violet specimens as amethysts, is now applied to the purple, blue, green, and other varieties, if they present an undulated structure. The cairngorm of Scotland, smoky quartz, rose or milk quartz, prase, siderite, chalcedony, agates, the onyx, cat's-eye, chrysophase, avanturine, plasma, heliotrope, or bloodstone, the opal, &c., &c., may all be categorised with quartz.

It occurs in igneous and metamorphic rocks; that is, those that have been the subject of the action of fire, and such as first begin to show that, although of the same origin, they yet adjoin such as indicate signs of life.

First in order of the rocks in which gold and quartz are discovered, may be named the granitic. Not that all granitic rocks contain these substances; for, in that case, our island would abound with them. For many miles, for example, between Dumfries and Wigton, in Scotland, the traveller by the railway passes through nothing but a wild granite country. In the north of Scotland, especially in Aberdeenshire, the same geological condition may be observed. Granite rocks are generally notable, on account of the sharp unmodified form they present; in many cases forming what are termed aiguilles, or the lofty needle-shaped peaks of mountainous districts, examples of which are abundantly found in the Alps; the Caucasian mountains in the south-east of Europe; the Altai range and the Himalayas, both in Asia; with many others, unnecessary here to specify.

Generally many valuable metal deposits are found in granite veins. This occurs with us in Cornwall, especially as regards tin-stone; and in Asia, Australia, Africa, and North and South America, such ranges of mountains as contain these veins are frequently rich in gold. The rocks of igneous origin are generally crystalline in their character, as evidenced in granite, &c. "The magnitude of the constituent parts varies exceedingly, the crystals measuring from several cubic inches to very minute grains in size. Their colour also varies considerably, being chiefly governed by felspar, which also determines, on the whole, the condition and appearance of the rock; since when that is apt to decompose, the whole mass is of comparatively loose texture, and falls asunder on exposure." It is from the decomposition of the felspar that we obtain the pipe-clay in this country; and in Australia pipe-clay is similarly discovered, but is often accompanied with gold.

We have already noticed that porphyry is very frequently the source, as a rock, of gold in the vein. In Mexico the most valuable metal mines occur in sienitic porphyry; but we have the same class of rocks in this island, that have, as yet, not shown any signs of metallic riches; hence the simple geological or mineralogical character of a rock does not necessarily predicate, under all circumstances, the possession of metals either native or in combination.

Basalt is a rock of igneous origin; and, in our islands, is illustrated in the celebrated Giant's Causeway, Staffa, &c., where basaltic columns of the most magnificent kind may be

noticed. Such rocks contain, at times, minerals; but being really of the nature of lava, they are not at all favourable for metal deposits. They form the dykes, faults, &c., of our mines, which have already been described in the chapter on Mining and Metallurgy. They are very frequently adjacent to our best mineral veins, however, in this country. For example, within a mile or two of Glasgow and its iron-producing mines, the trap rises to the surface. In some parts of Scotland we have seen trap coated with substances exactly like the scoriæ of the smelting furnace, or that of the steam-boiler furnace—clinkers adhering to the trap, just as fresh as if they had been formed at the present day, although, at a very high tide, the sea has broken over them for ages.

Metamorphic rocks are of two kinds—stratified and unstratified. Those of which we have hitherto been speaking are of the non-stratified class; that is, they do not occur in beds of regular inclination or position, but have been thrust up, in a molten state, through those that are properly stratified. Amongst the metamorphic class, are quartz rock, and crystalline limestone or marble, that are generally pretty well distributed throughout the surface of the globe. But of the most abundant of metamorphic rocks, are gneiss, and mica slate or schist, which, at p. 147, *ante*, we have described as, at times, containing gold in the matrix. In our own country, the west of Scotland and the north of Ireland afford many instances of this rock; and, as already stated, is at times the locality of gold. It occurs abundantly in our island, in Wales, the north-western counties of England, Devonshire, and in parts of Ireland and Scotland; and the best varieties of such rocks afford largely our means for roofing, cistern-making, paving, and other purposes of utility, of a similar character.

In reference to the age of these rocks, much difference of opinion has existed. In our former pages, we have pointed out, that whilst lead may be associated with mountain limestone in its geological relations; copper and tin with the Devonian, as an older rock than the preceding; tin associates with gold, to a certain extent, in the rocks to which we are now alluding. On the age and distribution of igneous and metamorphic rocks, Professor Ansted makes the following judicious but cautious remarks. Referring first to the metamorphic, he observes—"As a group they are very widely distributed—very closely related both to the underlying igneous, and the overlying aqueous rocks; singularly alike in many respects, over very extensive districts, and at vast intervals; and often covered up, superficially, by a great thickness of the rocks—apparently partaking of the character of universal formations. From all this, it might be imagined that they were contemporaneous, or nearly; that they form a vast mantle, spreading far and wide, and of much greater antiquity than any of those stratified fossiliferous rocks which, in most countries, are found upon the surface, in the plains, and in the valleys. But such a conclusion would be premature, and very unphilosophical. Whenever, indeed, we find fossiliferous stratified rocks resting upon metamorphic rock, and those again reposing on granite, the *relative* age is clearly exhibited—but only the relative age; and the metamorphic and igneous rocks may manifestly have been brought into their present condition at any period between the first creation of the earth, and the deposit of the lowest unaltered rock. As an example of this, we may take an instance occurring in the Alps, where a true clay-slate rests upon granitic rock; but there is distinct evidence, from fossils, that the slate is a very recent rock, geologically speaking. The slate of Wales, on the other hand, which hardly differs geologically, are among the oldest strata of which we have any knowledge, and were, most unquestionably, brought into their slaty condition long before the others (the Alpine) were deposited as mud.

"The igneous and metamorphic strata of one district, therefore, may be of very different ages from those of another, however closely there may be a resemblance of mineral structure. Chemical action may have been going on at great depth beneath the surface, continuously, during the whole of the earth's history, and may still be going on; so that the whole undulatory movement of the earth's superficial crust may have been the means of bringing successively, under the influence of heat, those substance deposited from suspension in water; and may, perhaps, alter them, first reducing them into metamorphic, and afterwards converting them into igneous rocks."

We have quoted a high authority in such matters; but cannot, at the same time, help reminding our readers that, after all, geology, although so greatly advanced of late years towards the position of an exact science, has yet much to accomplish before it attains that position legitimately. The late Sir Charles Lyell has remarked that, in respect to the age of rocks, and other matters pertinent to such subjects, it cannot but be felt that the greatest uncertainty still exists in the matter; "it is that wide ocean of scientific conjecture on which so many theorists, before my time, have suffered shipwreck."

Numerous specimens, and some large, of quartz, containing gold that we have seen, presented no indication of its existence therein to the naked eye; and such is of frequent occurrence. Generally, however, if any quantity of gold be actually present, a sense of weight is indicated to the hand; the reason of which is not due simply to the presence of the gold, but to its prevalence in one particular part, by which the centre of gravity of the mass is occasionally found distant from the geometrical centre, that would be its locality if the mass were homogeneous. At times, the gold runs in thin veins quite through the mass, and is evident at different parts of the exterior.

The treatment of gold, as obtained from the rock or matrix, in nearly every respect resembles that of silver, in regard to stamping, crushing, amalgamation, &c., and these subjects will

be fully dealt with when we describe the processes used for the extraction, &c., of that metal.

Turning now from the production of gold, we may next glance at a few of the uses to which the wants or fancies of civilisation have applied it.

In all departments of working the precious metals, repetitions of methods previously explained are involved—such as cutting, hammering, beating, rolling, wire-drawing, chasing, &c., &c. But, with gold, its great value demands much care to prevent waste; for whilst in the metals previously described, a loss of a few pounds in weight is attended with no serious result, the price of gold varying, for pure, from twopence, to jewellery gold at a penny, per grain, becomes a matter of serious pecuniary consideration.

And first in respect to the ordinary method of valuing gold, as employed for various purposes. It has been already stated that pure gold is far too soft to permit of its being used unalloyed; and, therefore, a portion of copper forms a constituent of all gold used for coin, jewellery, plate, &c. Standard gold consists of eleven parts of gold united with one of copper. But, technically, the value of gold is distinguished by its fineness in *carats.* Twenty-four of these, each weighing twenty grains, weigh one once troy, the standard by which all the precious metals are estimated by weight. The gold coin of this realm is hence called "22 carats fine;" that is, it contains twenty-two parts, or carats, of gold to two of copper. Absolute, or chemically pure gold, would consequently be twenty-four carats fine; because the entirety of an ounce, or any other weight, would be composed of it alone. Therefore, generally, a statement of the fineness of gold in carats expresses the fractional value. In respect to the proportion of gold present, $\frac{22}{24}$ would represent the gold value of sovereigns and half-

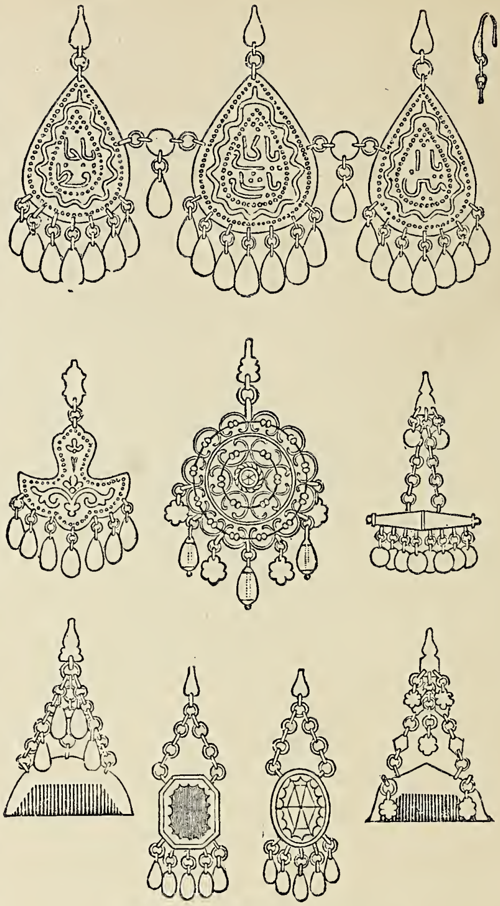


Fig. 144.—Egyptian Jewellery.

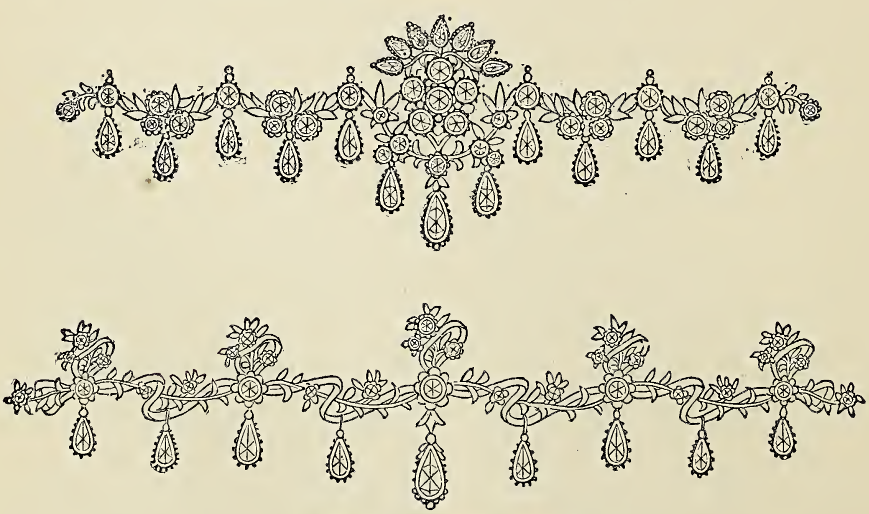


Fig. 145.—Egyptian Jewellery.

Fig. 146.—Egyptian Jewellery.

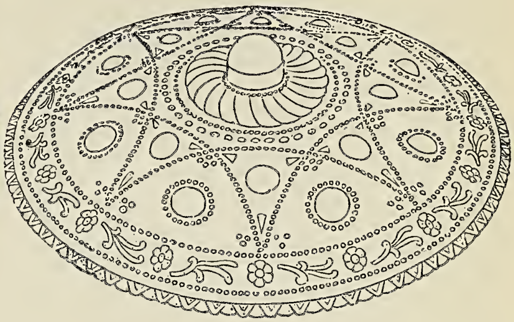


Fig. 147.—Egyptian Jewellery.

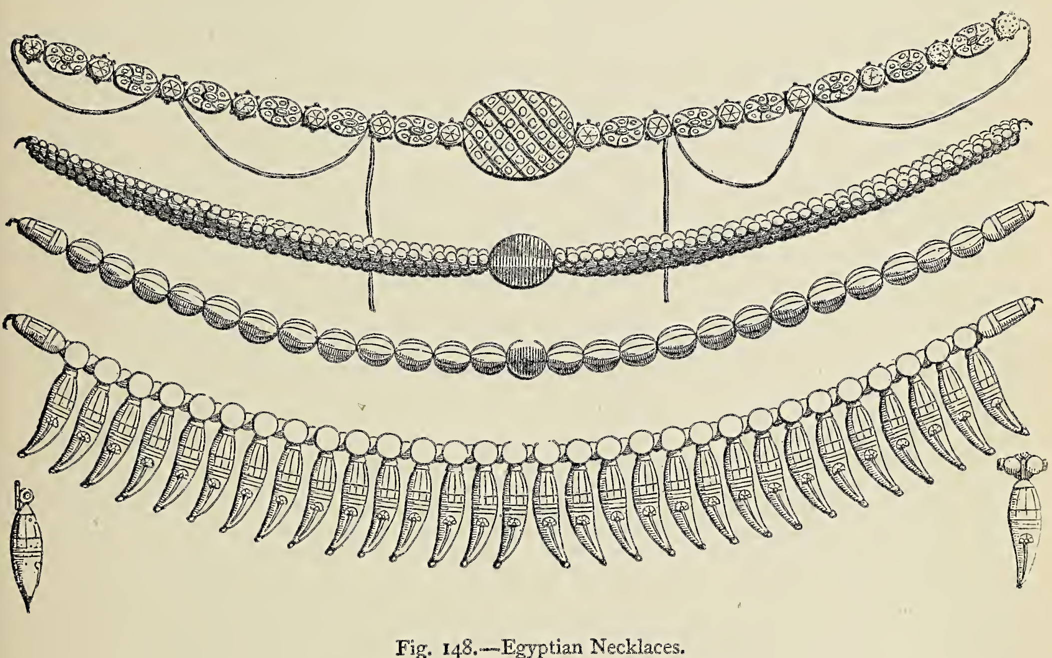


Fig. 148.—Egyptian Necklaces.

Fig. 149.—Egyptian Nose-rings.

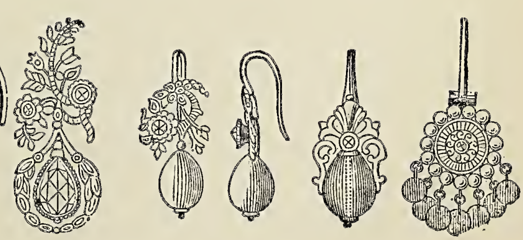


Fig. 150.—Egyptian Ear-rings.

sovereigns; $\frac{18}{24}$, that of eighteen carat gold, in which six carats of copper are present, and an alloy much used in making watch-cases and various objects of plate and jewellery. Hall-marked articles of gold thus express the amount of the metal used in them; the stamp of the Goldsmith's Company being impressed as a guarantee of the value.

Apart from "hall-marked" goods, or coin, the purchaser of articles in gold has no guarantee of the amount of the pure metal contained therein. In fact, jewellers' gold where the metal is *really* present, is an article of the most variable constitution, running from the standard, or $\frac{22}{24}$ kind, down to a limit so remote, that the gold itself used may be all but infinitesimal in amount.

In forming ornaments of gold, setting precious stones, &c., numerous mechanical processes are involved, the details of which would demand too much space for their adequate description. From filigree, the finest in structure of gold-work, to the massive plate of the sideboard or table, an almost endless succession of means are adopted, in respect to variety and number, in pleasing refinement of taste. Usually, in jewellery and ornamental gold-work, the expense of labour, especially in chasing, far exceeds the value of the gold emploeyd; but such articles are, unlike plate, not sold by weight, but at fancy prices. Thus, a chased ring, or pot of silver, and even copper, may not, taking the ratio of price of the metals in relation to that of the workmanship, be much less, in cost, frequently greater, than such made of gold.

The fabrication of personal ornaments and articles of luxury from this metal is carried on very extensively in our own day. Many such articles are made of solid gold, whereas others are formed mainly of some cheaper material, coated on the surface with gold. *Gold-lace* may be regarded as a striking example of the latter kind; since it is very beautiful in appearance, and yet consists really of gold only to an extent so minute as almost to surpass belief: this can only be understood by describing briefly how gold-lace is made. Gold-lace consists of threads of silk: these threads being twisted or woven together in a peculiar manner. Every thread is bound round from end to end with a coil of gold-wire; and even this wire, so far from being pure gold, is merely an exceedingly thin layer of gold placed upon a centre or core of silver wire. In the first place, a rod of solid silver is prepared, about two feet long by one inch in thickness; this is heated over a charcoal fire, and is then covered with a coating of leaf-gold, which is burnished down securely upon it; upon this another similar coating is applied, and so on until five or six thicknesses of leaf-gold have been used, by which a thickness is attained sufficient for the object in view. The quantity of gold thus applied is not much more than a hundred grains to a pound of silver. The silver is annealed, and is then brought into the state of fine wire by a wire-drawing process very similar to that which has been described in respect to copper, iron, &c.; it is first reduced by successive gradations from the thickness of an inch to that of one-fifth of an inch; and is then worked through holes smaller and smaller in diameter until it becomes as fine as a hair, which hair-like filament is bound round the silken thread to make gold-lace. Now, this wire, no thicker than a hair, is made mainly of silver, the thickness of which is enormously greater than that of the gold that envelopes it; for it will be remembered that there was in the first instance only a hundred grains of the latter to a pound of the former. It has been calculated that the exquisitely fine film of gold thus obtained on the surface of the silver-wire for gold-lace is not thicker than one-third of a millionth part of an inch!

A second mode, in which a thin film of gold is made to do duty instead of a larger substance of the metal, is by the process adopted in cheap jewellery, and which is exemplified in the gilding of buttons, briefly noticed in a former page. Here the gold is made to combine into a paste with mercury and other chemical agents; and this paste being thinly applied to the surface of the object to be gilt, a subsequent heating drives off the mercury and chemical agents, and leaves the gold in a very thin film on the surface. It is stated that five grains of gold, worth fifteen pence, is in this way frequently made to gild a hundred and forty-four buttons, each an inch in diameter. But this plan has been almost entirely superseded by the modern processes of electro-gilding and electro-plating, methods which have already been frequently mentioned in former chapters, but which will in all their detail be fully described in a separate chapter.

Jewellery, properly so called, is however an art of somewhat higher pretensions, since it involves the use of solid gold, or a least of gold having the same quality throughout the substance of the articles made. Jewellers' gold is seldom quite pure, but is combined with other metals of lower price. There is a curious set of terms employed in designating the quality of gold. In the gold coinage, for instance, as the pure metal would be too flexible to bear the hard usage to which coin is exposed, it is alloyed with a little commoner metal, to give it an increase of hardness. The English legal "standard" for coin-gold is expressed by the fractions $\frac{11}{12}$, or $\frac{22}{24}$, or by the term "twenty-two carats fine." This means that there are, to every twenty-four carats, or equal parts of the metal twenty-two of "fine" or pure gold; the remaining two parts being a mixture of silver and copper. In goldsmith and jewellery operations, in like manner, the quality of the gold is expressed by stating the number of "carats fine" which it contains. Some jewellery is said to be made of "fine gold;" and this, if the term be correctly employed, would refer to gold really pure; but such is not the case, for it seem to imply merely the best or finest which jewellers are in the habit of using, and which contain about two-thirds of pure gold. Indeed, pure gold would not be hard enough for such manufactures. Jewellers' gold varies from this quality downwards, by indefinite degrees, and to an indefinite extent, as already mentioned.

Only a junta of jewellers, dress-makers, and ladies' maids could give a complete catalogue of the numerous ornaments of gold and silver which have of late been added to the dress of our females in the higher circles of society. Ornaments for the head, including large combs of gold, necklaces and brooches of extended size, clasps and buttons of gold to fasten the bodies of the gowns, bracelets and armlets, additionally numerous rings on the fingers, gold hooks and eyes for the drapery of the gowns, eye-glasses set in gold and secured by chains of gold, and a watch with gold seals, and trinkets too numerous to be mentioned by one not professionally a master of dress. Such are some of the uses of gold for purposes of ornament, but their number is "legion" and therefore we must refer our readers to catalogues published by modern jewellers to fill up the void we are compelled to leave.

But these include only those instances where *bonâ fide* gold is the material of the decoration: another section is becoming, commercially and artistically, every year more and important. The ornaments of this kind are first fabricated of fine gold, and commonly in London alone: they are, however, soon imitated by other workmen in gold of inferior quality, in some degree of inferior workmanship, especially at Birmingham. At the latter place much gold is so mixed with alloys, in the combination of which much chemical knowledge is applied, that it can be sold at all prices from a half to even a quarter the cost of standard gold.

The operations of the working goldsmith or jeweller consist of a minute imitation of the processes of metallurgy generally. Rolling, stamp-wire-drawing, filing, hammering, riveting, soldering, burnishing—all are followed to a greater or less extent; and all are the work of men, who confine their workshop arrangements within a a very small space. The sorts of articles produced by these means are, in our own country, too well known to need description; and as to foreign countries, we may assume that wealthy Europeans generally, whether of England or elsewhere, soon copy each other's tastes in respect to these kinds of decorations. As to countries further from home, we may gather a hint or two from the wood-cuts, Figs. 144 to 150 inclusive; given at pages 160 and 161. Most of these relate to Egyptian jewellery, such as Mr. Lane describes as being worn by the higher class of Egyptian females in modern times.

Gold-beating may, from its importance, be first briefly glanced at. To produce gold leaf, machinery other than a rolling-machine in the first states, and subsequent beating with the hammer, has not, and perhaps never will be, employed, simply because the operation must necessarily be of a gradual nature. The gold for the beater is slightly alloyed with copper and silver, to give it sufficient hardness to withstand the operations to which it has to be subjected; but the copper does not exceed more than $1\frac{1}{4}$ per cent. of the precious metal. The alloy, when cooled after melting, is milled or rolled between steel rollers, so as to form it into a flat ribbon. This is cut into pieces, and hammered on an anvil until a piece an inch square does not weigh more than six grains. A packet of these squares is made up, interlayered each with a sheet of vellum; and the surface of them is then extended by hammering, until each piece occupies about sixteen times its former area. Cut up into a fourth of its size, the plate is hammered under surfaces of the intestine of the ox, known as gold-beater's skin; and the process, thus continued, is not terminated until the gold arrives at such thinness, that 250,000 or 300,000 leaves so produced must be piled on each other to produce a height of one inch. In this condition some leaves, although perfect—*i.e.*, without crack—are semi-transparent, showing a greenish light to the eye; doubtless complementary, optically speaking, to the natural yellow colour of gold.

While speaking of jewellery it may be desirable here to give a few remarks on the "Precious Stones" used for the purposes of ornament.

First, in beauty and value of all gems, is the diamond, which is simply carbon in a crystallised form, and belonging, in crystallographic arrangement, to the cubic system. It is the hardest of all known substances, and can only be cut or polished by its own powder. It is chiefly obtained in Asia, Australia, and America, and varies in size from an object almost too minute to be seen, to the Koh-i-noor, which, before cutting, weighed $186\frac{1}{2}$ carats, and the value of which is all but fabulous. The "Star of the South" is valued at no less than one million sterling. Of recent years a large number of diamonds have been found in Cape Colony, in fact, to an extent which has seriously lowered their market value.

The mode of obtaining diamonds greatly varies; but generally is similar to that already described as adopted in gold-washing. Professor Ansted thus describes the methods adopted in India, &c.:—"They occur in gravel, generally near the banks of streams, or in mud-banks, sometimes of great extent, in the district whence they have been generally obtained. * * * * The process of exploring is exceedingly simple, and the only tool employed is a sharp pickaxe. With this, men dig into any promising spot, and deposit on the banks of the river all the mud and sand they get up. There it is looked over by the women and children of the tribes, who, for this purpose, take a plank, five feet in length by two in width, hollowed out in the middle, and furnished with a rim on each side, three inches in height. They place this plank in a position a little inclined (just enough to allow water to run off); heap upon it mud and sand dug from the river, and continue for some time to pour water upon it. As soon as the water runs away perfectly clear, they anxiously look over the hard stony matter which is left upon the plank, and pick out all loose pebbles and larger pieces of gravel; these they throw away; and the remaining mass, consisting of smaller grains, they remove to another plank of the same form as the first, but smaller, and carefully spread it over the surface, so that every particle can be separately examined; this

they do one grain at a time, throwing away all that is stone or gravel, and laying aside every particle of gold, or crystal of diamond. They usually contrive to place the board so that the sun shall shine upon it at a certain angle during this operation, by which every particle shall be well illumined. The earth chiefly sought after, and most accurately examined, is a red ochry clay, containing a small proportion of sesquioxide of iron: in this the diamond is most commonly found; though, as it is sometimes met with in the loose mud, the whole is well washed and examined."

Diamonds are cut into various forms, the two most common of which are the rose and brilliant. The "rose," or "rosette," is so named because of its partial similarity to an unopened rose-bud, and is generally followed in cutting the cheaper kinds of diamonds. "It is a sort of pyramid, with a flat base, and inclined facets, terminating upward in a pointed apex. The flat base is imbedded in the setting; and, therefore, in the rose diamond, the whole of the stone appears projecting above. The "brilliant" is the more valuable form; it may be considered as formed of two pyramids connected at their bases, the apex of each truncated or cut off, and the sides worked into facets, as in the case of the rose. The stone is held in the setting or broadest part, or junction of the pyramid; one pyramid spreads upward in sight, the other is hidden below, so that only half the stone, or somewhat less, appears; but the hidden part is most powerfully effective in adding to the brilliancy. The apex of the pyramid is cut off to a considerable extent, and the large facet thus formed is called the *table:* the corresponding facet below, formed by the truncation of the lower or hidden pyramid, is much smaller, and is called the *collet.* The rim where the setting takes hold, or the junction of the basis of the pyramid, is called the *girdle.* There are thirty-two facets cut round the upper slanting surface of the stone—namely, between the girdle and table—and twenty-four on the lower part; that is, between the girdle and collet. All these facets have names, by which they are known to the cutters; and all the dimensions of the stone should, in order to produce the best effect, bear certain definite proportions to each other. The most favourable form of brilliant for exhibiting the lustre of the stone is considered to be the square, having the corners slightly rounded off; but, of course, many stones will not admit of being cut to this form without loss; therefore round, oval, pear-shaped, &c., are, perhaps, most common. The stones lose about 50 per cent. in cutting, more or less; so that to make a brilliant of one carat a rough stone of two carats is required. The weight of the Koh-i-noor, before cutting, or rather re-cutting, was 186½ carats; but, as now existent, it weighs only 106, having lost 80½ carats in that operation.

In respect to the prices of diamonds, it may be observed, that although it is generally stated that they increase in value as the square of their weight in carats, the back-scenes of diamond-dealing reveal some remarkable falsifications of such a rule. An enormous difference subsists between the pawnbroking and diamond-dealing fraternity in respect to such prices, and those given by the "public" for these gems; and if the latter knew a little more of the secrets of the diamond trade, its fabulous greatness would speedily vanish.

All the other gems but the diamond are composed chiefly of silex and alumina, either separately or in combination, and with the addition of colouring and other matters in much smaller proportion, derived from metallic oxides. Occasionally diamonds are coloured of a yellow, and even black tint; the latter arising, not from any chemical difference in the constitution of the stone, but simply from the mechanical arrangement of its particles. In a similar way black flint becomes white when pulverised; and almost any coloured glass similarly becomes white when reduced to powder.

Next to diamonds, the emerald, ruby, and pearl are the most valued gems. The finding of emeralds and rubies is mostly conducted in the same manner as that of diamonds. In respect to the pearl-fishery, it is unnecessary for us to burden our pages with the often-told tale of the method adopted on the Ceylon shores. Pearls are generally supposed to be produced by a kind of oyster; but really the "fish," more properly, belongs to the mussel family. We have, however, at this moment before us a very pretty pearl obtained from a Whitstable oyster; so that the oyster tradition is by no means belied. Indeed, pearls *may* be produced by any of the *mollusca,* that line the inside of the shell with what is generally considered a "pearly" surface. Of late years, Scotland and Ireland have produced a large amount of pearls from various species of the mussel family, or *Mytilaceæ,* some of them being worth as much as £50 each. In many of the rivers in Scotland, pearls have been obtained where the mussel is abundant: at places on the sea-coast, a person may walk over acres of ground covered with mussels at least a foot in depth. Chemically, the pearl is chiefly a carbonate of lime united with a small amount of animal matter; hence it is soft, and liable to injury from abrasion, &c. Artificial pearls are largely manufactured from the scales of a species of carp, the *Cyprinus alburnus,* or bleak. The scales being powdered, afford what is called the *essence d'orient;* and this is ingeniously attached to the inner surface of glass beads, that may thus be readily and effectually made to imitate the real stone.

It may be here noticed, that the beautiful play of colours in the pearl, mother-of-pearl, and some other precious stones, is not natural, but accidental; and arises from the presence of exceedingly narrow fractures, by which white light is decomposed, and the various colours consequently afforded. Some years ago, a most ingenious adaptation of this peculiarity of surface, was made in the manufacture of Barton's button, which merely consisted of a piece of highly polished steel, on the surface of which very fine lines were drawn—so fine, in fact, as to decompose light, and produce all the play

of colours noticed in mother-of-pearl, which arise from the same cause. The colours of the soap-bubble; of tar or oil dropped on water; of thin plates of air produced by pressing a convex lens on a flat piece of glass, and known as Newton's rings—all proceed from the same cause.

Precious stones of a mineral nature—that is, apart from pearls formed by animal secretion, or the diamond, which may be practically considered of a vegetable origin—are exceedingly numerous; and are, almost invariably, of a crystal nature.

Some very interesting experiments were undertaken, several years ago, by Mr. Crosse, who attempted to produce crystals of some of our most precious gems by the action of very intense currents of voltaic electricity, passed through solutions containing the different constituents of such bodies. His success was partial, but encouraging; and there seems little doubt that long-continued voltaic action, under such circumstances, would produce crystals of many mineral substances found in nature. It has even been attempted to produce diamonds artificially; and an interesting communication was made to the Academy of Sciences at Paris, on July 30th, 1866, by M. Lionnet, "On the Natural and Artificial Production of Crystallised Carbon." M. Lionnet takes a sheet of platinum foil, and a sheet of tin foil of rather smaller dimensions, and rolls them together loosely. The roll so made is placed in some sulphide of carbon. A feeble electric current is thus generated, whereby the sulphide of carbon is decomposed. The sulphur so set free, combines with the tin, which is, of course, thus constituted the positive plate of this elementary battery, or cell, whilst the carbon aggregates in crystals that fall to the bottom of the vessel. Other methods have been tried, but they have all practically proved failures.

The following are amongst the chief of the precious stones in use for jewellery and ornamental purposes, not previously described in detail. The list embraces most, if not all, the stones so employed.

Rubies and sapphires are varieties of corundum, one of the hardest minerals known. The Oriental ruby, when perfect in colour, transparent, and of good size, almost equals the diamond in value. Blue sapphires, cut perpendicularly to the axis of the six-sided prism, present, occasionally, a bright opalescent star with six rays, and are hence called star sapphires. The chemical constituent of all these varieties is chiefly alumina. Spinelle is an aluminate of magnesia, affording the spinelle ruby, which is a highly-prized gem, but softer than the Oriental ruby. The scarlet variety of spinelle affords this gem; the rose-red, the *balas ruby:* the yellow, or orange, the *rubicelle;* and the violet-coloured, the *almandine ruby.*

Amongst stones composed of silicious matter entirely, or with small admixture of other substances, and belonging to the quartz, are the following. The amethyst has a violet, purple, blue, white, yellow, and green colour, although, at one time, the violet kind alone had the name of amethyst applied to it. Chalcedony consists of crystalline and amorphous quartz; the red, brown, and yellow varieties are known as carnelians, the yellow also being called sardes. The rich colour of the Oriental carnelians is due to their being heated, by which they are converted from a dark gray to a fine red. Agates are composed of layers of chalcedony of various colours; as is also the onyx. Cat's-eye is also conposed of chalcedony, of a brown-red or green-gray colour, penetrated by amianthus. Chrysoprase is composed of silica, but coloured by the oxide of nickel. Plasma is a green variety of chalcedony. Heliotrope is chalcedony coloured by a green earth, with yellow and red spots of jasper, which is chalcedony rendered opaque by a mixture of iron and clay.

The opal is a species of amorphous quartz, some varieties of which have a fine mixture or play of colours, that renders them valuable as gems. Of this class are the fine opal, or girasol; the noble, or precious opal; the common, or semi-opal; the cacholong; hydrophane, so called because, although opaque in air, it becomes transparent when immersed in water; and wood-opal, which has apparently a wood-like structure.

Chrysolite is a compound of magnesia and silica, and is prized as a gem when free from defects, and of a good colour. The hyacinth is a variety of zircons, that are so called when transparent and bright-coloured. Moon-stone is a transparent, colourless variety of felspar, a compound of alumina, silica, and potash. Some specimens of *augite*, if transparent, form handsome stones, varying in colour from the green of the emerald to the yellow of the topaz. It is also a silicious mineral, and may be formed artificially, by fusing together silica, lime, and magnesia. Idocrase is used for a variety of purposes of an ornamental nature, and is known under the name of hyacinth, chrysolite, &c. The garnet is of several varieties, also silicious, and is known as almandine, the common garnet, the brown garnet, the black or melanite, topazolite, a yellow variety; cinnamon stone, and pyrope. If of a good colour, it affords a frequent substitute for the ruby, and becomes of considerable value. The *sapphire d'eau* is a blue transparent variety of a silicious mineral known as *cordierite*, and found in Ceylon.

Amongst the most beautiful of all gems is the emerald, which, in addition to alumina and silica, contains the rare earth glucina. The beryl, or aquamarine, is of a similar composition. A fine large emerald almost equals a diamond in value; but it is a stone rarely free from flaw.

The tourmaline is of especial value in optical science, on account of its peculiar effect in polarising light. Blue, green, and brown transparent crystals of it are, however, prized as gems; and, occasionally, are substituted for, and sold as, emeralds, sapphires, and topazes. The yellow variety is considered as valuable as the latter stone.

The turquoise, chiefly obtained from Persia, is

much valued as a gem, and is a phosphate of alumina. A variety, called occidental turquoise, is obtained from Lower Languedoc, and consists of bone, coloured with phosphate of iron. The topaz is of various colours, and consists of alumina, silica, and iron. By heat the yellow varieties are turned red. The purest kind, obtained from Brazil, and known as *gouttes d'eau*, may, by proper cutting, be made to resemble the diamond in lustre and brilliance; and the Brazilian variety, made red by heat, so closely resembles the ruby, that it can only be distinguished from that gem by the fact of its becoming electrical by friction.

Amber, of occasional use for ornamental purposes, is not legitimately a stone, being a kind of fossil gum-resin, thrown on to the coasts of many parts of Europe, and also found in tertiary strata or beds. Besides its ornamental uses, it is of great value as a constituent of the best kind of varnishes.

The preceding account embraces nearly all of the "precious stones" in ordinary use for ornamental purposes. But to this list we may add malachite, granite, fluor spar, alabaster, serpentine, galena, and many other mineral substances that, by the art of the lapidary or jeweller, may be rendered pleasing to the eye. Jet again, with coral, and, indeed, a host more substances, might be mentioned that are so employed; and many such, by careful and artistic treatment, become of great value, owing to the amount of labour bestowed on them. Ivory, lapis lazuli, granite &c., are often worked up into ornamental objects; but the use of all these materials much depends on the caprice of fashion. Thus, many years ago, coral was highly esteemed—at least the red variety. It then fell into disuse, again to be resumed as an article of ornament; and, very recently the delicate flesh-coloured kind attained a price for or five times as high as gold, but it aftewards again fell in disuse.

Silver.

The treatment of gold "ores" in most respects is followed, as a general principle, in obtaining silver from its ores. Stamping, crushing, washing and amalgamation being the principal operations. At pages 153 and 157 appear illustrations, kindly supplied by the proprietors of *Engineering* of the Cerro de Pasco mining district of Peru. We are also indebted to *Engineering* for the following description of these mines, and the operations carried on for the production of silver.

"Cerro de Pasco is situated on the Andes range of mountains in South America at an elevation of 14,500 feet above the sea level, and about 150 miles west of Lima. The town contains some 20,000 inhabitants, all more or less connected with the silver mines of the neighbourhood. Callao is the shipping port for Lima, Cerro de Pasco, and the adjacent district.

"Up to a recent date a bridle road or mule track was the only route between Lima and Cerro de Pasco whereby goods or machinery could be transported, and this limited the size and weight of every package to a single mule load, the maximum weight of which could not exceed 300 lb.; it is preferred by the mule drivers to take two articles of 150 lb. each, which may be slung on either side the mule, to one weighing 275 lb., because the mule carries his double load more easily, and the difficulty of loading and unloading is vastly diminished when light packages are carried, and when it is borne in mind that several days are occupied by the journey this becomes an important consideration.

"The nature of the country makes the transport of all materials extremely difficult: at one point of the route an elevation of 16,000 ft. has to be surmounted, and at several places the track would admit of only one mule passing at a time.

"The above-named route is now nearly out of date, the Oroya Railway, which has been constructed from Lima to within 90 miles of Cerro de Pasco, takes the bulk of the trade as far as it goes, and the last 90 miles is still done by mules, which limits the usefulness of the railway, and is very little help towards diminishing the enormous cost of transport.

"The cost of mule carriage from Callao to Cerro de Pasco was equal to £3 15s. per mule load, or £27 per ton, and the cost is now very little less by railway and mule. The new railway has been constructed in a very ingenious manner, and gullies are crossed and rock pierced in a manner only seen in precipitous mountain districts. The gradient is surmounted by means of zigzags.

"The climate is remarkably healthy, extremes of temperature are unknown, but constant and rapid changes take place, snow and sunshine alternating, the former very rarely lies upon the ground more than a few hours at a time; high winds are seldom heard, the normal condition of the atmosphere being extremely tranquil. Thunderstorms of a violent character, but of short duration, are frequent, and deaths by lightning are comparatively numerous. Earthquakes, although destructive and violent on the coast, are as rare as they are in England, the enormous weight of the mountains seeming to act as the weight of a safety valve on the volcanic region. The barometer at Cerro de Pasco stands with little variation at 17·30 inches to 18 inches which gives an atmospheric pressure 8·5 lb. per square inch as against 14·7 lb. at the sea level. Water commences to boil at temperature of 186 degrees Fahr., or 26 degrees below the boiling point at the coast.

"Cerro de Pasco lies about the centre of a rich mineral district which bears every indication of being the crater of an extinct volcano; it contains copper, lead, tin and silver ores in vast abundance, the latter metal being that chiefly worked. The other minerals named are practically of little value, owing to the difficulties and expense of land carriage. Coal in great abundance, and of almost all descriptions, from bog coal and cannel to semi-bituminous or anthracite is found a few miles from Pasco, and is carried on the backs of llamas driven in droves like sheep; each llma carries about 100 lbs.

The cost of coal delivered in Pasco is about £2 10s. per ton.

"The principal argentiferous veins of the district cross one another at the town of Pasco at an angle of about 70 deg.; the first, or leading vein runs from north to south to an ascertained length of about 3,500 yards by 130 yards wide, the other runs in a west-north-westerly direction; the length has been traced for 2,100 yards, and breadth 126 yards; from these main arteries smaller veins branch off in all directions.

"The silver mines, so-called, are mere surface workings, more like enlarged rabbit warrens than anything else; some are entered by surface holes, often covered by the miner's hut, and from holes excavated on the premises of the mine-owner. These holes frequently "cave in" and bury the unfortunate Cholos. The mining, such as it is, is done by the natives, a diminutive race of Indians; the silver ore (which is in appearance a kind of brown gravel) is brought to the surface by these men on their backs in leather bags or skins. Europeans or natives of the low countries are incapable of prolonged exertion in the rarefied atmosphere of the Cerro; a difficulty of breathing effectually prevents new comers from active exertion, such as they have been accustomed to in localities of moderate elevation, and this will be more readily understood when it is borne in mind that Cerro de Pasco is within 500 ft. of the summit of Mount Blanc. The ore contains from 30 to 60, and sometimes more, per cent. of silver, and when brought to the surface is deposited in a heap near the hacienda, preparatory to its undergoing the first process, which is grinding by immense edge runners of granite 8 ft. to 10 ft. or 12 ft. in diameter and 18 in. to 20 in. wide. These stones are quarried at about 42 or 50 miles from Cerro de Pasco and are transported over a rough country in rather a singular manner. A square hole is made in the centre of the stone, and a long beam wedged in, projecting about 3 ft. through the stone; at the other end of the beam a small rough kind of wheel is put on, revolving on the beam, this also has about 3 ft. of the beam projecting through it, and a bridle chain is looped over the two ends; then a team of 24 to 26 oxen and bulls are yoked on, and as many as 48 oxen may be seen occasionally yoked to one stone. In this way the stone is dragged over a wonderfully rough country; and the descent of steep places is no less singular. The stone is brought carefully to the edge of the declivity, the oxen yoked the opposite way, then a lever tilts it over the edge, and the bulls ease it down backwards; sometimes the stone proves too heavy and overpowers the bulls, dragging the whole team down the hill in a helpless mass. The treatment the poor animals get at the hands of the natives is abominable, but the drivers manage them wonderfully, and seem to be able to get the stones over almost impossible obstacles. Each of these stones will last from six to eight months according to quality, and when worn down to about 5 ft. diameter, they are taken out and converted into bottom stones or saucers. The cost of these stones is a very heavy item in the expenses of the hacienda or establishment, the value in place being nearly £80 each.

"The ore is ground in the saucers by the edge runners, till it is sufficiently fine to flow away with the water into receivers over the edges of the saucers: a constant supply of water is given while the grinding process is going on. After the ore is ground as described it is conveyed to circular yards called "circos," each about 36 ft. in diameter, paved with stone, and enclosed by a dwarf wall about 3 ft. to 3.6 ft. high. The ground ore is spread over the entire floor of the circos in the shape of thick mud to a depth of some inches, the whole is then closed with salt, lime, quicksilver, copperas, and water. Eight horses or mules are brought into each circo and driven round and round to mix the whole up together; the driver stands on a stone in the centre. This process is continued during thirty or forty days, the stuff is then washed in a running stream between the circos, in which pots are placed at intervals to catch the metal, and when collected from the pots it is filtered through large cone-shaped bags suspended from the roof of the buildings; the bulk of the mercury is by this means allowed to drain off into vessels placed to receive it, and is recovered for future use; a large percentage is of course lost. The residuum is turned out on a skin-covered table, and moulded into brick-shaped cakes, which are piled upon the floor in the form of a cylinder, and then covered by a wrought-iron bell open at the bottom; a charcoal or coke fire is then built round the bell, and the quicksilver remaining in the amalgam is driven out by the heat and falls into receptacles placed beneath to receive it. The silver which remains has a porous and beautifully frosted appearance, and is taken to the smelting-house, assayed, and run into ingots or bars, when it is ready for the market. The machinery employed at the mines is chiefly for grinding the ore, and all the haciendas except the Hacienda Esperanza use water power. The latter is chiefly owned and managed by English, and is the only establishment where steam power is employed. The above sketch of the several processes of reducing the ore to the silver of commerce will make it understood that the grinding process is of considerable importance.

"At a depth of 150 feet to 200 feet water is met with, and the deepest workings have yielded the best ores. Many attempts have been made to drain the mines by pumping machinery, and much was done with that object, shafts sunk, and machinery erected; but difficulties of transport, the apathy of the Peruvians themselves, and jealousy of foreigners, have hitherto made all these attempts abortive. Ores of great richness are known to exist below the water level. It is stated that some years ago an iron bucket was fished up from the bottom of a shaft coated with silver like thick electroplate.

"The processes for reducing the ore, it will be remarked, are of a rude and primitive description. The difficulty and expense of introducing anything new or uncommon into this region is extremely great, chiefly owing to the

wonderful stupidity and ignorance of the native Indians, who are capable only of doing the meanest labour; they are, in fact, little better than beasts of burden. Europeans have to be sent out expressly to erect machinery, and the cost of passage out and home, the high wages paid them, 12s. per day to fitters, smiths, and masons, and the difficulty of controlling these men, where there is no competition, offer very serious obstacles in the way of all improvement. Various attempts to drain the district have been made, and ended in failure; the last and best scheme, that of Mr. Meiggs, was brought to an abrupt stop by the death of that gentleman; this scheme was an adit driven at a sufficiently low level to drain all the mines. It will be resumed some day, and then the vast wealth of the district will be developed. Salt mines are worked at a distance of a few leagues in the same primitive fashion as the silver mines.

"The collieries are wonders of abundance. One colliery is a mass of coal of unknown depth and thickness worked by free level; all the coal is brought out on the backs of the miners, except at the colliery of the Hacienda Esperanza, where a light hanging railway is in use, and this has only lately been introduced. The fact of the railway not being completed from Lima is seriously detrimental to the welfare of the place. In the hands of Englishmen or Americans this wonderful region would have produced untold wealth, but in the hands of Peruvians no progress can be hoped for or expected. Nature's gifts are most abundant. Mineral wealth of all kinds is there ready to hand; all that is wanted is rapid and cheap transport to the coast, but while the vain Peruvians are electing or deposing presidents, fomenting revolutions, and making war on neighbouring states as vain and insignificant as themselves, the development of the mineral resources of their country is neglected, and the energy and capital of foreigners who attempt it are wasted and made abortive by the crass ignorance of a proud and indolent race of people by whom it is the misfortune of the country to be governed.

At page 156, *ante*, will be found an illustration of the method of treating silver-tailings as carried on in Nevada, U.S.A. We are indebted to *Engineering* for that illustration, and also for the following description by Dr. T. Egleston of it. We may first explain what is meant by "tailings."

"In every silver mill there are two streams, discharging one from the battery, and one from the settlers. As they are treated differently, different names are given to the residues which accumulate from them. The pulp which runs out of the settlers and agitators is called "tailings." That which comes from the stamps, and is not deposited either in the pulp or slime vats, is called "slimes" or "slums." The tails have been in contact with mercury, the slimes or slums have not. There are thus slimes from the slime vats in the mill, which are treated with the pulp, and slimes outside of the mill, which if caught are collected in reservoirs. The part of the pulp which has been reduced to a slimy condition in the pan, is called pan slime, and hence there are three kinds of slimes: mill slimes, collected in the slime vats of the mill, which are treated in the pans; battery slimes, which are the overflow of the slime vats; and pan slimes, which discharge from the agitators with the tailings, and are only accidentally separated from them in the lower parts of large reservoirs. The battery slimes are usually allowed to escape, or are caught in large reservoirs below those of the tailings. The pan slimes and tailings are treated together in concentrators, or on blanket sluices principally, to catch the mercury and amalgam, and heavy particles of ore, and the concentrates are treated in pans.

"If the ore has been properly worked in the (amalgamating) pans, no gold or silver can be extracted directly from the tailings and pan slimes. It is in a state of sulphurets, which cannot be separated without thorough oxidation, produced either by roasting, by chemical action, or long exposure to the action of the weather. They contain, however, a certain portion of mercury and amalgam, and sometimes sulphurets containing gold which will pay to concentrate and separate.

"The battery slimes are poorer than the ore, but they generally will assay about 60 per cent. of its value. They contain proportionately much less gold than the ore. The quantity of slime depends upon the amount of water used in the battery, the method of settling, and the quantity of clay in the ore. With hard ores, the amount of slimes in the best mills will be 2 to 3 per cent., with soft ores it will be more than double that quantity. Whatever gold there is in them is very flaky and likely to float; the silver is in a very fine state of division and also likely to float, and is also to some extent in the form of sulphurets. The slimes are worth from 15 dols. to 20 dols., and often more, and can be profitably treated. When water is scarce the slimes are very advantageously treated without any special arrangement being made for it, as all the water from the slime vats is pumped up with the slimes in it, and passes again through the mill.

"By this method, there are no battery slimes. It is well worth consideration whether this method would not pay even when water was plenty. The amount of water to be paid for would be less, and the gain in yield would probably more than pay for the pumping, if properly managed.

"The pan tailings and slimes could be caught with a sufficient number of tanks, but the mills have not usually been built with reference to it, and could often not be altered, as there is generally not sufficient space around them for the purpose. Frequently the slimes are not valuable enough to justify much expense, so that in most of the mills only a rough attempt is made to catch the mercury and amalgam, and very large quantities of them go to waste.

"The treatment of the slimes varies but slightly from the treatment of the ore, differing

only in these respects, that pans of much larger dimensions are used, and the slimes do not require grinding.

"Generally the battery slimes are settled in a series of reservoirs. The richest material will always be in the first one. There are a large number of such slime reservoirs of great extent, that have been filled to the depth of 8 ft. to 10 ft. in Dayton Canon, below Virginia City, Nevada, where a number of mills have been established to treat them ; but the best of them do not get more than 60 per cent. of the assay of the slimes, even where they use very large amounts of chemicals, as most of them do. The bullion produced is never fine, and is less so as the amount of sulphate of copper is larger. The loss of mercury is so great that some of the tail mills (as mills treating tailings and slimes are called) purchase ore to mix with them. This loss has given rise to the invention of a number of machines for saving it.

"The tailings are generally treated in blanket sluices, the attempts to treat them on concentrators not having been successful. The sluices are troughs 20 in. wide with sides 2 in. or 3 in. high, and sometimes 1,700 ft. or 1,800 ft. long, with a grade of 6 in. to 10 in. in every 12 ft. ; a number are usually placed side by side, generally three. Sometimes as many as 15 to 20 and even more are arranged together. They are covered with strips of coarse blanket, which are laid on the sluice, and can be easily removed to be washed. When the sluices are long, they are tarred on the underside to keep the blanket from rotting, in which case they are nailed to the sluice and swept. When not tarred they are taken up and washed. The tarring is done by drawing the blanket over a bath of hot liquid tar."

Passing over, for want of space, some other interesting matters, we quote the following description of the Woodworth Sluices. Dr. Egleston remarks :—

"The best example of long sluices is the Woodworth sluices of Dayton, Nevada, which were designed and constructed in 1874 by W. H. Armstrong, for the Dayton Mill, of which he was superintendent. They are the largest which have ever been built, and are designed to treat all the tailings from 25 to 30 mills in Gold Canon, or 262 stamps, being an average of two tons a day for each stamp. These are all collected in the sluice at the Bacon French Mill. This sluice is 18 in. square, $3\frac{1}{2}$ miles long, with an average grade of 4 in. to the rod. It is never cleaned, but carries the collected tailings to the Woodworth sluices, of a portion of which we have given a perspective view on page 156, *ante*, and which are composed of 12 sluices, S, side by side, each one of which is 19 in. wide. They are separated by strips of wood $1\frac{1}{4}$ in. wide, and 3 in. high, and form together a table 22 ft. wide and 1,700 ft. long. These sluices have a grade of 2 in. to the rod, and are supported on trestles $4\frac{1}{2}$ ft. apart. For convenience of working, the group is divided into sections of 150 ft., but each sluice is continuous. At the head of the sluice the tails are discharged from the sluice A into a head-box B, made of two compartments included in the same structure. These are each 3 ft. long and 2 ft. deep, and the whole width of the sluices. The bottom of the first one, B, is 20 in. above the bottom of the sluice, and has three openings, 3 ft. wide and 4 in. high, which discharge into the distributing box C, which has 12 openings, 4 in. by 8 in., one for each sluice. All the openings in C are provided with gates D, so that all or any number of them can be closed at a time. In front of the box B is another one E, of the same size and shape, which is fed by clear water, from the two lines of galvanised iron pipe F, 5 in. in diameter and 2,156 ft. long on one side of the sluice, and on the other supplies it through the gate S, to the side box H, which is $8\frac{1}{2}$ ft. wide and $10\frac{1}{2}$ ft. deep, and carries the clear water to the head of the sections; it is consequently 150 feet shorter than the whole sluice. Here it discharges through the openings L into boxes M, 6 in. by 6 in. which cross the sluice at right angles, and have, like the clear water head-box E, a 3 in. round hole one for each sluice, which can be closed with a plug when the blankets are not being washed. These troughs are 1 ft. above the sluice, and are supported on four inclined pieces shaped so as to leave the current free. At the end of each section, there is a slot K in the bottom of the sluice, 3 in. wide and 17 in. long, closed by a sheet-iron cover, which opens into an inclined sluice 6 in. wide and 12 in. deep, which runs under the whole width of the table, and at right angles to it, and discharges into a trough O of the same size, which runs parallel to the table, and carries the concentrates to the reservoirs. This slot in the bottom of the sluice is closed when the sluice is working, and the blanket laid over it, as at the Eureka Mill.

"At the end of 1,200 feet there are ten settling tanks, 9 ft. long, 8 ft. wide, and 4 ft. deep, into which the sweepings are discharged. At the end of 1,600 ft., there are two of the same size, and at 1,700 ft. two more, making 14 in all; 140,000 ft. of lumber, 24,000 ft. of blankets, 19,000 ft. of which are in use at a time, 2 tons of nails and spikes, and 1,600 gallons of coal tar were used in the construction of the sluice." The total cost of construction was 21,500 dols.

From the foregoing descriptions our readers will learn much of the minutiæ of the treatment of silver ores as adopted in North and South America, and they may be taken as illustrating the methods almost invariably adopted where silver is derived from its own ores, and not from lead.

The manufactures of silver are, in nearly every respect, carried on in a manner similar to those of gold. Practically, in fact, the operations of the goldsmith and silversmith are identical, as both metals are subject to the same mechanical treatment of drawing, hammering, &c., &c., and produce precisely similar results. Electro-plating is an art that, although not more than forty years old has made wonderful progress; and, to a large extent, has driven out of

the market such materials as Sheffield plate, German and other "silvers," Britannia metal, &c. In a subsequent chapter all the details of electro-plating, &c., will be given. When silver is to be deposited, the battery or trough solution is composed of the cyanide of silver; and when once this is prepared, nothing is more easy than to coat, to any desired extent, a polished metallic surface with the metal. This method has the great advantage of being completely under control; and when the silver has been worn away it can be instantly renewed. Silver so deposited has a much whiter appearance than the ordinary metal used for coin, which, like standard gold, is an alloy of copper, and made for the same reasons; for silver is too soft to stand the wear and tear which it would be subject to, either as coin or plate. British standard silver, as used for coins, consists in the proportion of eleven ounces two pennyweights of pure silver to eighteen pennyweights of copper; that is, 37 of silver to 3 of copper.

In respect to the amount of manufacture, that of silver must necessarily take precedence of gold; for, putting aside the electro-deposition just alluded to, plated articles and articles of silver-plate are always in great demand. Besides possessing the valuable qualities of gold in many respects, except that of colour, it has the advantage of being greatly cheaper—its average price not exceeding a fifteenth of that of standard gold. Like the latter metal, it can be beaten into leaves that are exceedingly thin; but not near so much so as those of gold.

Among other general uses of silver, that in connection with photography must not be omitted; more especially as, of late years, it has become highly important, absorbing annually many thousand pounds worth of the metal. Its use in photography depends on the fact, that certain of its salts, and other combinations, are instantly affected by light, and become darkened. The nitrate is universally employed as the most eligible salt; and from this the chloride, iodide, bromide, &c., are readily prepared on the surface that is to be made sensitive, by first impregnating the latter with chemicals containing chlorine, &c. This prepared surface, on being immersed in a solution of the nitrate of silver, instantly becomes sensitive to the action of light; and hence the photographic views, likenesses, &c., now so popular.

This art, however, is of but recent origin; and, indeed, fifty years ago, was like the electrotype, electro-plating, gilding, &c., quite unknown; or, at least, although its principles were investigated cursorily by Davy, not the least practical result thereby accrued. The subject of photography, in its details, will become the subject of a separate chapter. In medicine, the fused nitrate affords the *lunar caustic* of pharmacy. Beyond the chemical combinations of silver, already noticed, there are none applied to any specially important office in arts or manufactures.

Mercury.

The ores of mercury have been already described, the principal one being cinnabar, which is found, together with the metal, in a fluid state in the veins of mines. After washing, to remove the earthy matter and the free metal, the ore is heated with iron-filings, which attach to the sulphur, leaving a sulphide of iron, whilst the metal distils off, and is condensed. It is imported into this country in bottles of wrought-iron.

In this condition it is far from pure, being mixed frequently with other metals. By fresh distillation it may be much purified, but not completely, owing to the volatility of bodies with which it is mixed. Perfectly pure mercury, prepared by agitating it with a mixture of two parts of nitric acid to one of water, and leaving the mixture for a few days, with occasional stirring, and subsequently washing, separating and drying the metal, keeps its polish for any length of time. If, however, any other metal be present, it soon tarnishes, and loses that roundness of surface that is so characteristic of the pure metal, and having which, it posseses a kind of repulsion to a glass surface; that is changed to an adhesive inclination, if lead, &c., be present, or dissolved in it.

Next to its use for silvering looking-glasses, already described, mercnry is most important in the construction of the barometer and thermometer, owing to its fluidity at all ordinary temperatures on the earth's surface, and the wide range that exists between its boiling and freezing-points—viz., from 40° below zero, to 650° or 660° above it, according to the scale of Fahrenheit, and giving an entire range of about 700°. Its sulphide, vermilion, affords a splendid red pigment; one of its chlorides, *calomel*, is an important agent in medicine; the other chloride, *corrosive sublimate*, a deadly poison, is of restricted medical use, and of much value as a preservative of animal substances, from its solidifying their albumen; hence it is employed in solution, for that purpose, by taxidermists. Many other preparations of mercury are of medicinal use; and formerly it was considered as a specific for syphilitic disorders.

It has the curious property of promoting a large and rapid creation of saliva; and hence its use in salivation and the injurious effects on persons engaged in operations connected with it as a metal. We have largely described its use in the present chapter for amalgamation, in obtaining gold and silver from their ores, for which it is employed in Mexico, California, &c., where, of recent years, it has been discovered, but not in equal abundance to what has been described in respect to the mines of Idria and Almaden. Indeed, it is the most rare of all ordinary metals in respect to its distribution, and, consequently, unlike all, except tin, that have hitherto been described.

For the following description of the treatment of mercurial ores in North California we are indebted to a paper by Dr. T. Egleston, published in the columns of *Engineering*, from which we make the subjoined extracts:—

"The practice of the Redington with the old Idria furnace is the best example of non-con-

Mark Firth.

tinuous work in shaft furnaces. These are the largest works in Northern California, and are likely to have no rival except, perhaps, at the Sulphur Bank mine. As everything relating to this variety of furnace, which is destined in future years to disappear altogether, is of historical interest, I have given a few details of the New Almaden furnace of the same general type, which I visited shortly after, though it is south of San Francisco.

"The most important question in the metallurgy of mercury is condensation, and it is of even more importance than the construction of the furnace. The two questions are, however, intimately connected, and are engaging the serious attention of all persons interested in the metallurgy of mercury.

The Redington Quicksilver Company own a large property, or hacienda, which has been called Knoxville, and a small village connected with their works is known as the Redington mine. They formerly had at this mine two modified Idria furnaces, which have since been reconstructed into Livermore's fine ore furnaces. These furnaces were situated within a few feet of the ore shaft. The mine produces 700 to 800 tons of cinnabar per week. It occurs in serpentine. A very large quantity of high grade ore is found, but the average yield of the mine is about 3 per cent. Cinnabar and metacinnabarite are both found crystallised in considerable quantity. Epsomite resulting from the action of iron pyrites on the serpentine is also found in very great abundance in acicular crystals over a foot long. The ore is very intimately associated with iron pyrites. About one-tenth of it comes from an opening made in the side of the hill. From the mine the ore is dumped on to screens, two of which are placed one over the other. The upper screen is made of bars $1\frac{1}{2}$ in. in diameter, 2 in. apart at the top, $2\frac{1}{4}$ in. at the bottom. The screen is 8 ft. long, 5 ft. wide at the top, and $5\frac{1}{2}$ ft. wide at the bottom. What passes over this screen only is hand picked. What passes through falls upon a wire screen of $\frac{3}{4}$ in. mesh. What passes this screen goes directly to the furnace, and is charged with hand-picked ore. What passes through it is treated as fine ore. All the large pieces are broken by hand. The fine ore was formerly made into adobes, which were used in the modified Idria furnaces exclusively. No dirt is mixed with the adobes. The ore is so filled with an easily decomposing iron pyrites that the action of the water effects a partial decomposition of the magnesian rock that binds the particles together.

"Under ordinary circumstances, but for the large amount of magnesia present, the pyrites would disintegrate the rock. The adobes are made in wooden frames roughly put together by the workmen, and intended to be 9 in. by 4 in. by 4 in. When such adobes are dry they weigh about 12 lbs. They are sometimes made 12 in. by 5 in., by 5 in., when they weigh about 25 lbs., which is an unusually large size. The smaller size is the one most generally used. Seven men at 2 dols. per day can make 6,000 adobes; each man can mould 1,000, but six men require one helper. The adobes therefore cost about 2·33 dols. per thousand. The actual cost is difficult to ascertain, for adobes are not like ordinary ore which can be dumped anywhere. They are really more tender than ordinary sun-dried brick. They are generally made during the dry season only, and they must then be carefully stored in sheds until wanted. They will therefore have to be handled at least three times after being made, once in storing, once in being removed to the furnace, and once in charging, which causes many of them to break up and become entirely reduced to powder and useless; broken in two or three pieces they still can be used, but there comes a limit when the pieces are too small, which limit is reached all the more rapidly as the adobes contain less binding material. No account is usually taken of this loss; it has not been considered worth while to estimate it, and it will probably never be done, as in the future, adobes will probably not be made, as some of the best metallurgical ability in California is being expended on special furnaces for the treatment of fine ores. The cost of the adobes, delivered at the furnace ready for charging, as near as can be estimated, including making and storing them, is about 5 dols. per thousand."

Dr. Egleston then gives an account of the construction of the furnace which, for want of space, we are compelled to omit. The method of charging it, reducing the ores, condensing the mercury, &c., he relates as follows :—

"The ore is charged by a windlass from above (into the furnace); the buckets used for charging are of iron, 3 ft. in diameter and 30 in. high; the adobes are charged on platforms 3 ft. by $2\frac{1}{2}$ ft., and $2\frac{1}{2}$ ft. high, that carry 150 adobes weighing about a ton. To make the charge the ore compartment is first lined with adobes two to five thick, piled together, but not crowded close. Inside of this the ore is placed in pieces from a size not larger than 12 cubic inches, down to one-quarter of this size, in layers 18 in. to 20 in. in thickness. Adobe channels are then built, communicating with the openings in the wall of the fireplace and condenser side of the furnace. Their number depends upon the size of the ore, four for coarse and five for fine ore. They are made as flues to carry the heat into contact with all parts of the ore, and also have the effect of preventing the charge from packing together. A part of the soot that either has been worked, or is too poor to work in the retorts, is charged over every layer of ore. A new layer of ore is then put in over the adobe channels, and so on, until the chamber is nearly full over the top; fine ore mixed with poor soot is placed, and the whole is covered over with clay and ashes, which the heat bakes, so that it becomes hard after the furnace has been fired a short time.

"When the charge is being drawn these compartments are closed on the top with cast-iron pans, which are either filled with water or covered over with ashes, in order to prevent the heat of the charge setting fire to the building above. The joints between the pans and the

masonry are made tight with ashes to prevent the escape of the fumes. These pans are 5 in. deep, $4\frac{1}{2}$ ft. wide, and 10 ft. long. They are provided with two eyes on each end, so that they can be removed by a crane.

"One furnace is charged Monday, and is fired Monday night, and kept burning until Thursday morning. Two cords of wood are burned during this time. The sulphur takes fire and answers for fuel for the most part, for there is always an excess of sulphur as iron pyrites in the ore. The other furnace is charged Tuesday and fired Tuesday evening, and kept burning until Friday. One furnace will thus be cooling on Saturday and Sunday, the other on Sunday and Monday. A small quantity of mercury runs in on Tuesday, and in the first, second, and third compartments of the main condenser. It runs most freely Wednesday and Thursday. By Thursday a very small quantity of mercury is condensed in the extreme end of the condenser; 150 to 200 flasks are collected from both furnaces during the week, most of it from the fifth and sixth condensers. On Wednesday it commences in the fifth and sixth, and runs from this point until the furnace is discharged. Most of the mercury is obtained when the furnace is cooling down. When the draught is good, and the ore of moderate richness, the yield will not be less than 200 flasks per week."

Gold and Silver Assaying.

One of the most important operations in the application of chemical analysis to metallurgy, is that of assaying the value or character of alloys of gold and silver. It has been previously stated, that, in working these metals, but especially gold, the amount of the latter varies from absolute purity, or twenty-four carats, to comparatively nothing in some of the alloys employed. But even a minute quantity of gold, too small to be of the slightest value in respect to all other metals, often makes an alloy of value. Thus it is worth while for metallurgists to refine some dollars in circulation gratuitously, in regard to their usual charges, because they can recoup themselves by the trifle of gold that such coins contain. In regard to silver, although of much less value than gold, still its price is far beyond any metal that can ordinarily be met with as alloy. Of course, here we except platinum and its allied metallic bodies.

As with all other substances, various methods may be employed for assay of alloys of gold and silver; but practically, we may reduce them to two—namely, the wet and dry methods. By the wet method, the alloys are first dissolved in an acid, and then thrown down by a suitable precipitant. After careful washing and drying, the amount of metal present is readily ascertained by simple proportion, and regard to the law of chemical equivalents, when silver is dealt with; or if gold be precipitated, it is recovered in the metallic state. The dry method involves the process of cupellation; and we shall briefly detail the principal features of both plans.

The moist method, in respect to gold, may be very shortly disposed of, confining our attention simply to alloys of that metal with silver and copper; inasmuch as the mode of operation has been already described at p. 151, *ante*, so far as qualitative analysis is concerned; and the only further steps required are those of filtration, washing, ignition, and weighing.

In respect to the moist method with silver, volumetric and ordinary means of analysis may be employed. The removal of silver is easily effected from almost any solution, because it affords an insoluble precipitate of the chloride that can only be confounded with that of lead. The latter, however, is soluble, to a certain extent, in water; and may, therefore, be removed by long washing. Or, if the chlorides of lead and silver are simultaneously precipitated, that of silver can be extracted by means of cold liquid ammonia, in which it is soluble, whilst the chloride of lead is not; and the chloride of silver may then be precipitated by adding to the ammonia solution nitric acid and common salt.

In round numbers, 144 grains of chloride of silver contain 108 grains of silver; but, more exactly, the constitution of the chloride is—

Silver	108·0 grains
Chlorine . . .	35·5 ,,
	143·5

These proportions nearly give the per-centage of each element at 75 per cent. of silver, and 25 of chlorine. More exactly, the per-centage is, of—

Silver	75·26
Chlorine	24·74
	100·00

It is evident that the preceding facts may be adapted to various modes of analysis, which our limited space forbids us to describe. The volumetric method is simply arrived at, bearing in mind that 58·5 grains of chloride of sodium (pure common salt) afford sufficient chlorine to form an insoluble chloride, with 108 grains of metallic silver, as above. Thus, if 58·5 grains of chloride of sodium, in solution, be added to a solution of 170 grains of nitrate of silver—in which there are, of silver, 108 grains, oxygen 8, and of nitric acid 54; total, 170 grains—143·5 grains of chloride of silver will be precipitated, and a correct analysis effected. The volumetric method is especially valuable in testing the strength of the silver bath to the photographer, to whom it is always a matter of importance to ascertain such a point correctly.

Connected with the subjects just discussed, are the methods of recovering silver that has been dissolved in the cyanide of potassium, for electro-plating, and other operations carried on in the arts. Several methods have been proposed for this purpose; amongst which are the following:—

First, "plated silver," such as is used in making Sheffield plate, is, in that form, a sheet

of copper, on which another of silver has been soldered, and the two rolled together as one, an external surface of silver on the copper being produced, so as to form the exterior of the "plate." As the silver wears off, the copper surface becomes exposed, except at the outer edges of the plate, which are generally made of standard silver, soldered on, because at these edges the silver is most rapidly worn, ordinarily, and by cleaning. The silver may be readily recovered by an operation called "stripping." For this purpose nitrate of potash (nitre, or saltpetre) is dissolved in strong sulphuric acid, aided by heat, by which a certain quantity of nitric acid is set free, and held in solution. The "plate," on being immersed in this, has all its silver dissolved, whilst the copper is but barely acted on, any sign of which will be indicated by the solution becoming of the characteristic colour (blue) of copper solution, either without or with the addition of liquid ammonia, which should be done by putting a drop of the solution on a white plate and then adding ammonia. If the action is too slow, more nitre must be added, and a slight heating will facilitate the solution. From the latter the silver can be precipitated as chloride by common salt, after abundantly diluting the liquid with water. The copper will remain in solution. The chloride of silver thus produced may be reduced by washing and drying; and subsequently heating it highly with carbonate of potass in a crucible, when metallic silver will be obtained.

The following methods have been recommended for the recovery of silver from electro-plating solutions in which a portion of copper may be present, owing to articles made of that metal, brass or its other alloys having been plated therein:—Add hydrochloric acid until the liquid exhibits a strongly acid reaction. The precipitate of chloride of silver which is then obtained will be of a reddish-white colour, because of the cyanide of copper which is precipitated with it, when the solution has been used for silvering objects containing copper. In this precipitation by hydrochloric acid there is hydrocyanic acid vapour set free; therefore the operation should only be performed in the open air, or under a laboratory hood for carrying off the dangerous fumes. If the precipitate be very red it must be treated with hot hydrochloric acid, which will dissolve away the cyanide of copper. The chloride of silver having been abundantly washed with water, and dried, is to be put into an earthen or porcelain crucible with borax, and ignited in a furnace, when metallic silver will be reduced.

This method is very simple in its application, and very economical, considering that, by the aid of hydrochloric acid, all the silver contained in the solution of cyanide of potassium is precipitated, and there remains no trace of it in the liquid. But the large quantity of hydrocyanic acid vapour which is disengaged, is a circumstance that must be taken into serious consideration when operating on large quantities of silver solution, for it is most deleterious; and nothing but the most perfect ventilation, combined with arrangements for the escape of the poisonous exhalations, will admit of the process being carried on without great danger to the operator. The liquid should be operated on in large vessels, because of the great amount of vapour produced.

We may add a word or two of caution, by way of addition to the preceding. In all processes where the cyanide solutions of the metals are used, the greater the surface exposed to the action of the air, the more hydrocyanic acid gas is evolved; and hence a vessel eighteen inches in diameter, filled with the usual silver-plating solution, will soon, if in active operation, fill even a good-sized room with the hydrocyanic acid to a dangerous degree. The same observation, of course, holds good in regard to the cyanide of potassium fixing solution of the photographer. Therefore, in addition to every precaution for effecting complete ventilation, it is also prudent to have a bottle of liquid ammonia always at hand, for application to the nose, by which much of the danger may be obviated. The effects of hydrocyanic acid are very insidious; its smell of bitter almonds, unless very strong, not being generally objectionable; but, even to the slightest extent present, it acts on the brain, consequently on the nervous system, and, at last, on the heart, producing langour and sickness, that becomes distressing, even if attended with no worse consequences. For precisely the same reason, the fingers should never be immersed in any cyanide solution. If they have been they should be immediately washed in abundance of water.

The dry way of extracting silver from a cyanide solution is that of evaporating the latter to dryness, and fusion of the solid at a red heat. The fused mass is then to be cooled and washed with water, when most of the silver will be obtained in the metallic form as a porous mass. What little silver has escaped reduction by this method may be recovered by adding hydrochloric acid to the wash-water, to precipitate it as a chloride, and reducing this by any of the methods already pointed out. Before describing the dry method of gold and silver assay or cupellation, the best plan of recovering gold from its cyanide solution may be conveniently here explained, as it is merely a modification of the moist or wet method of analysis.

Numerous plans have been devised; for whilst, as we have seen, silver is readily precipitated from cyanogen by hydrochloric acid, and reduced, gold under certain circumstances is difficult to deal with. The following affords a general account of some of the methods adopted to recover the gold. The first presumes—as will frequently happen in gilding solutions, and equally in the assay of gold ores, to which the process is, therefore, indirectly applicable—that silver, copper, and iron are present.

The liquid—the same as with the cyanide solution of silver, already dealt with,—is acidulated with hydrochloric acid; in which case there is produced hydrocyanic acid gas, which requires the same precautions in ventilation previously directed. This addition of hydrochloric

acid causes a precipitate, which may, according to circumstances, consist of cyanide of gold, cyanide of copper, and chloride of silver. The precipitate, washed and dried, is to be boiled in nitro-hydrochloric acid (*aqua regia*), which dissolves the gold and copper in the form of metallic chlorides, and leaves the chloride of silver unaffected. The solution, after filtration, to separate the chloride of silver—which should be washed, and the washings added to the above—should be evaporated nearly to dryness, in order to drive off excess of acid ; it is then dissolved in a small quantity of water, and the gold precipitated from it by the addition of protosulphate of iron. The gold will then be obtained as a brown powder. If, as is most probable, a little gold be left in the solution, this may be evaporated to dryness, fused, thrown on a filter, and washed, when any gold is recovered. The chloride of silver is to be reduced by means already directed.

There are various ways of recovering gold from solution by the dry method ; and of these we shall select the following :—The solution of cyanide of potassium, that contains gold, silver, and copper, is evaporated to dryness ; the residue fused at a red heat ; cooled and washed (the wash-waters still containing a little gold and silver ; and this occurs most often when the solution of either metal contains a very large excess of cyanide of potassium). The residue, after washing, consists of gold and silver in a porous metallic state (the cyanogen affording the reducing agent), and carbide of copper, resulting from the decomposition of cyanide of copper by heat. The metallic residue is treated by nitro-hydrochloric acid, which forms an insoluble chloride of silver, and contains the chlorides of gold and copper in solution. From this the gold is precipitated as a brown metallic powder, by protosulphate of iron, as already indicated.

Another plan, that of Professor Bœttger, is to fuse the dry residue—obtained by evaporating the cyanide solution, as just directed—with its own volume of litharge, in a covered crucible, when an alloy of gold, silver, and lead is obtained. If this alloy be treated with nitric acid, of the specific gravity 1·20, and heat be applied, the gold separates as a brown metallic powder, whilst the lead and silver remain in solution as nitrates. From this the silver is easily separated by hydrochloric acid, after the methods already frequently directed.

By the dry plan, all offensive and dangerous evolution of hydrocyanic acid is avoided ; and generally, by due care, the gold and silver may be completely extracted.

A very ingenious method has been proposed by the celebrated chemist, Plattner, applicable, in part, to the preceding purposes, and also to the estimation of the per-centage of gold in crushed quartz. It is briefly as follows :—The ore is crushed to a very fine powder, and about two pounds or so are weighed off. It is then to be well roasted, to drive off sulphur, arsenic, and any other volatile substances. When cooled, the powder is transferred to a tall glass cylinder, filled with water, at the bottom of which is an opening, through which chlorine, in the gaseous state, is to be passed ; and the top of the jar is to be closed, except by a tube there inserted, by which excess of chlorine is allowed to pass off. All gold contained in the ore is thus converted into the chloride. The contents of the cylinder are then transferred to another vessel, leaving the powder behind, which should be abundantly washed, and the washings added to the first solution. By adding protosulphate of iron to this, the gold is obtained in the usual manner.

We next proceed to describe the process of cupellation, as applied to gold and silver in alloys.

The success of cupellation depends on the fact, that gold and silver not being oxidisable by heat or air, or both in combined agency, neither of the metals have sufficient attraction to chemically combine with oxygen under such circumstances, although, as previously noted, silver absorbs it when in a fused condition.

Iron, copper, lead, tin, and zinc all readily unite with oxygen, even at ordinary temperatures ; but still more so when raised to a red heat ; and this result is exalted by a simultaneous passage of a current of atmospheric air over their heated surface. Indeed, the preparation of certain lead pigments depends on this fact, previously pointed out when we dealt with the oxides of lead, in their commercial applications.

It hence follows, that, by heat and free access of air, the metals copper, &c., just referred to, may be readily oxidised ; but, at the same time, if alloyed with gold or silver, or both, the latter metals are readily separated, because, under such circumstances, they are not oxidised. Hence a ready mode presents itself for the separation of the base from the precious metals.

This constitutes the essential point in the art of cupellation, which differs, however, in certain details in respect to the two metals.

The apparatus necessary for the operation, chiefly consists of the *furnace*, which must be specially constructed for this purpose ; a *muffle*, placed in the furnace in such a position, that whilst it is kept at a high temperature, an abundant current of air can pass through for the purpose of oxidating the lead, &c. ; and, lastly, of a *cupel*, or small vessel made of bone-ash, in which the operation of cupelling or cupellation takes place.

In the engraving, Fig. 151, an illustration of a useful form of a portable cupelling furnace is represented. But in the metallurgical laboratory, the arrangement is generally of a more fixed character, and is usually built for the purpose. When of the portable kind, as represented in Fig. 151, it is generally made of wrought-iron plate, which is lined with fire-brick. Doors are provided in such furnaces, to regulate the admission of air to the ash-pit ; to the muffle, which is inserted at A ; for the supply of free air at B ; and the smoke, &c., escapes by the chimney, C. The cut illustrates one of them, constructed of fire-clay entirely, which may be fed with charcoal, or charcoal and coke, as fuel ; and all the necessary operations

are easily and effectively carried on. The illustration affords an external and sectional view of such a furnace. Several different forms have been given to these, chiefly known as the London, Berlin, and French kinds. In any one of these, it is essential that the minor arrangements of ash-pit, door, &c., be such that the degree of heat to which the cupel is exposed should be under complete control, for that is a very essential point of success in cupellation.

The muffle (Fig. 152) is an earthenware, or fire-clay, vessel so made that a current of air shall readily pass through it; hence the openings at the side, as represented in the cut, which, whilst the muffle is kept at a high temperature, allow of constant passage of atmospheric air, to effect oxidation of the "base" metals.

The cupel is a little cup, generally made of the ashes of burnt bone, this material forming an excellent absorbent; occasionally, a mixture of bone and birch ashes is employed. It is desirable to have a mould for making the cupels. These moulds are made of various materials; and may be obtained of the philosophical instrument-maker, and others connected with metallurgical matters. The cupel may also be purchased ready for use, from the same sources or is easily made.

Besides the precedingly-described apparatus, an assay balance is of the greatest importance, because all the figure value of the results obtained will depend on its accuracy. Such may be purchased at prices varying from £3 to £30. And in respect to their purchase, we only add—*caveat emptor*. Of minor importance is a flatting mill, to roll out the alloy of gold and silver for parting, &c.; tongs for removing the cupel from the muffle; hammer for flattening the metal button produced; parting flasks, &c; and other apparatus of ordinary use in the laboratory for solution, precipitation, and such connected operations.

The material employed in cupellation to remove base metals, and afford a button of the precious metal, is lead; and it is so employed, not only because it is readily oxidised, but because its oxide is easily fusible. The lead should be *perfectly pure* or otherwise it might possibly add silver or other elements of disturbance. The alloy of silver, having been roughly estimated in respect to its fineness, is wrapped in a sheet of pure lead; the proportion of the latter greatly varying, and dependent on the estimated quantity of copper present. Indeed, the proportions vary from sixteen to sixty times that of the supposed quantity of copper to be removed. The lead and alloy (the latter of which is not used to a greater extent than about ten or twelve grains) are placed on the cupel, heated to redness in the muffle and in the furnace, previously described.

The operation commences with the melting of the lead, which subsequently becomes oxidised, and, associating itself with the copper, is fused. As this occurs, the oxides are simultaneously absorbed by the porous substance of the cupel, which acts like a sponge. When the silver is quite freed from both these oxides, it suddenly brightens, emitting a flash of light, which indicates that the cupelling is about finished; for, instantly afterwards, a rolling or vibratory motion, previously noticed, and attended with the evolution of fumes of lead oxide, ceases. Great care must be observed in withdrawing the cupel; because otherwise, the silver, becoming solid too suddenly, is liable to dart forth small portions, the loss of which would cause error in the assay. This arises from the fact that silver, in a melted condition, absorbs, although it does not combine with, oxygen; and the escape of this gas tends, at the moment of solidification, to drive out portions of the metal from the cupel.

The latter being brought nearer to the mouth of the muffle, and thus allowed gradually to cool, is afterwards removed; and the bead of silver being weighed, indicates, by the loss the alloy has sustained, the amount of copper or other readily oxidisable metal that had formed its part constituents.

Although this method of cupellation is chiefly adopted in estimating the value of a silver alloy (at least in this country), it is by no means to be accurately depended on, for many circumstances tend to vitiate a true result. Still, for all ordinary purposes, it is sufficiently near the truth. The wet method (already described) may be considered as all but accurate in the results it affords.

The assaying of gold, although in most respects resembling that just described as adopted for silver alloys, varies in certain important points. For rough results, a very ingenious mode is adopted; it is that of comparing the streak of any alloy offered for examination with that of one the standard carat value of which is known. For this purpose, needles are made of each successive carat value of gold below twenty-four carat, or absolutely pure gold. The alloy is rubbed on a piece of hard stone, and its streak is first tested with nitric acid, to ensure that the alloy offered is not of brass or other alloy of copper; in which case it would be at once dissolved by the acid. Failing removal from the stone's surface, the alloy streak is successively compared with those of the known alloys of gold in the needles just referred to, until that nearest corresponding to it is discovered. This method, as we shall presently see, can also be made a useful assistant in the process of gold cupellation.

If gold be merely alloyed with copper, then precisely the same process as that described for silver can be followed, because the only thing to be done is the removal of the oxidisable metal. Hence, if gold coin or plate to be examined contain only gold and copper, the method of cupellation just detailed answers. If, however, silver be present, then, like gold, it is not only non-oxidisable under such circumstances, but it forms an alloy with the gold, to the exclusion of the base or oxidisable metal, which we shall presume to have been removed as just suggested.

Gold, as we have frequently stated, is only soluble, when pure, in *aqua regia*, or nitro-hydrochloric acid; whilst silver is chiefly soluble

in nitric acid. If, in any alloy, an excess of either gold or silver be present, their separation becomes not a simple question of the individual or collective use of these acids, because the circumstances of the alloy may considerably modify the chemical action of the acids upon either or

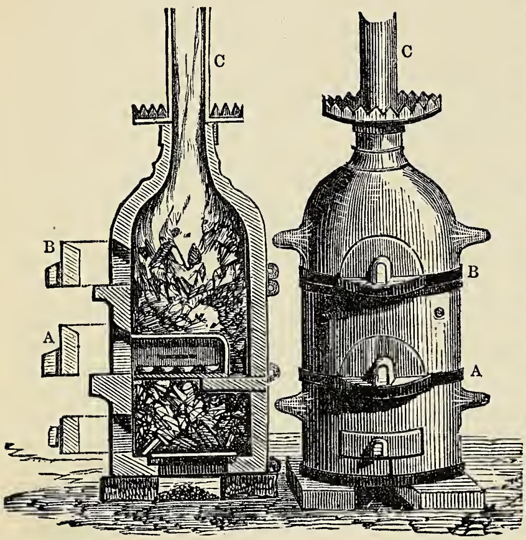


Fig. 151.—Cupelling Furnace.

both. Thus, if an alloy contain, say 15 per cent. of silver, the rest being gold, the latter metal is dissolved away from the silver by nitro-hydrochloric acid, or *aqua regia*, whilst the silver is precipitated as an insoluble chloride, and nothing remains but to filter and wash out the latter, and to precipitate the gold by proto-sulphate of iron—the weight of the two precipitates indicating, separately and collectively, their proportions individually present, which should collectively agree with the weight of the alloy.

If, however, such proportions of the two metals do not exist, and that the silver bears an inverse proportion to the gold—namely, about three parts or more, by weight, of silver to one of gold—then the silver can be dissolved away by nitric acid, leaving the gold untouched, and remaining in its metallic form. Hence the art of such an assay lies in so making an alloy of the silver and gold that the former may be dissolved away.

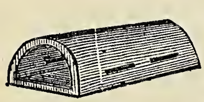


Fig. 152.—The Muffle.

The method adopted in usual practice is as follows :—The assayer, having formed a judgment, either by the needles already described, or by tact acquired by long experience, of the amount of silver that is present in the alloy under examination, fuses as much additional silver with the alloy as shall make the newly-formed one constituted of, at least, three times as much silver as of gold present—a method technically known as that of quartation, from the proportions—fourth parts—employed. The alloy is then enclosed in a fold of pure lead, generally procured by reducing the acetate of that metal, and exposed to the action of air and heat in the muffle, as described for the cupellation of silver. Thus all the oxidisable metals are removed, and an alloy of gold and silver left. Similar precautions having been adopted as were described to be necessary in respect to silver alone, the button produced is allowed to cool. It is then flattened with a hammer, and rolled out in the mill as already described.

By such means a thin flat ribbon of the alloy is afforded; the object of the operation of rolling being, to expose as much surface as possible in the subsequent operation of parting. This ribbon, being softened by heating it, is then made into a flat helix, called a cornet, and next boiled in nitric acid. Gradually the silver is removed, and the gold is left as a helix having no metallic appearance, because the particles are too far separated. It is, however, washed and fused in a crucible, when it regains the metallic appearance; and its weight will indicate that proportion in which it entered as a constituent of the alloy. The silver left in solution may be precipitated and weighed as chloride, the figure value of which indicating the amount of silver present, has been given at p. 172, *ante*. From this may be calculated the amount of silver present in the alloy, by deducting that added to it in the process of quartation; and the amount of copper present is, of course, resolved by the loss sustained during the cupellation. The three net amounts thus obtained should agree with the original weight of the alloy used, making the allowance for loss that necessarily will attend such repeated operations, and which will prevent absolute accuracy from being attained.

Several precautions beyond those already suggested must also be attended to. Of course the lead and silver employed must be pure before being added to the alloy that is to undergo cupellation. Again, the nitric acid employed to remove the silver must be as pure as possible; but especially free from chlorine or chlorides, otherwise the gold might be acted on, and its real proportion exhibited in less amount than was the truth.

The variation in value of both gold and silver, cannot be fully appreciated except by those practically engaged in such operations as are connected with the purchase of silver and gold, and bullion generally. It is true that a stock of the precious metals in this country is a pretty safe investment, and one that runs little danger of depreciation in price except as regards silver. Indeed, in respect to gold, the price, within this country's limits, is always fixed; that is, an ounce of standard $\frac{22}{24}$ carat gold will always be received at the Mint at a price represented by the figures £3 17*s.* 10½*d.*; whilst the average value of standard silver is little over or under 5*s.* In exporting or importing the precious metals, however, in any form, *not for use in this country,*

they can only be considered as an unmanufactured article, liable to all the events of trade in respect to variation of quantity, &c.; hence the assay of such commodities is a matter of great importance when the highest variation in standard quality is possible. It must be remarked, too, that foreign moneys are not equally as exact and regular in their proportions of alloy of gold, silver, or silver and copper, as our own. We believe that there is no instance that could be quoted, in modern times, of a depreciation of our gold currency in quality, whatever there might be in wear; but the latter is of comparatively small importance, in respect to our national honesty, because our gold coins are not legally circulated abroad as sovereigns and half-sovereigns, but simply as pieces of coined gold, the assay value of which, not the weight, is guaranteed by the impress of the stamp; for the export of our gold coin to foreign countries is not regulated by the nominal character of the coins, but by their weight, however much, by courtesy, they may be permitted to pass current in other states of Europe. Quality, therefore, is the essential point; that is, a uniform constitution in respect to the proportion of the constituents of the alloy.

Of course, certain precautions, that act also as a check on our coin production, must be observed; and the processes we have been describing are such as are, more or less, followed in the Mint of this country. But, as an external check, the *Trial of the Pix* was instituted. The *Pix* is a box, in which samples of the coin struck at the Mint are preserved, so that they may, at stated periods, be assayed and compared with the standard established by law. This assay is called the *Trial of the Pix*, and is carried out with many formalities, and with great exactness. The leading officers of the government, of the Mint, and a jury of the Goldsmiths' Company (one of the chief companies of the city of London) attend; and an assay of some of the sample coins is made. A report is then given of the result, and the limit of permitted variation between the quality of the alloy constituting the gold coin offered for examination, compared with the standard, is fixed (about the $\frac{1}{150}$th of the value); and no instance of the coin so tried is known in which this limit has been exceeded, or rather fallen beneath, so as to cause depreciation.

It must not be supposed, however, because the Mint buys gold, invariably, at the nominal price previously mentioned, that the value of gold is absolutely fixed, even in this country; although an ounce of gold is so considered as to be worth that value nominally. Like all other commodities, real or representative, it varies, evidently, or unnoticed, in price. In respect to Paris, Vienna, Amsterdam, and other foreign exchanges, of course, the reader of the daily papers will notice that such fluctuations are constantly going on. Indeed, the evident mercantile value of gold, as existing between this and other non-British countries, is as changeable as the daily weather, or the rising and falling of the mercury in the barometer; for, like the latter, its price is sensitive to the slightest influence of expansion or depression of trade. But, confining our attention to home, it must be remembered that a large proportion of both the gold and silver coin in circulation, has, from wear and tear, become little better than tokens; at least, so far as the smaller silver coins and half-sovereigns are concerned. It is not, however, the Mint price even that is a real evidence of the value of gold amongst us. The rise and fall of prices of other commodities are its true test; accompanied, at the same time, with the condition of the discount market, and, consequently, of public commercial confidence. Nothing, indeed, can be more puzzling than the absorption of the enormous additional quantity of gold that has left the crust of the earth, to do the work of a circulating medium, since the discovery of gold in California, Australia, Columbia, &c. It is a difficulty that the most astute financier or statistician has yet to solve, and, perhaps, that never will be satisfactorily determined.

But, in endeavouring to show the importance of the art of assaying, we have been led to verge on a discussion of some of the doctrines solely belonging to political economy, and there we must abruptly end. Suffice it to say, that as far as history, with any degree of accuracy, informs us, the relative value of gold and silver has varied from about $7\frac{1}{2}$ to 1, to $15\frac{1}{2}$ to 1. The following is a brief account of some such variations:—

In Persia, 3,000 years ago . . .	13	to	1
,, Ancient Greece	12	,,	1
,, Alexander's time	10	,,	1
,, Rome, time of Julius Cæsar .	10	,,	1
,, ,, afterwards reduced to .	$7\frac{1}{2}$	,,	1
,, England, end of 15th century	10	,,	1
,, ,, middle of 17th century	$15\frac{1}{4}$	,,	1
,, Portugal, at the same period .	16	,,	1
,, Other parts of Europe, at the same period	15	,,	1

In respect to the use of gold and silver for coining, our remarks must be very brief; for a full description of the process would necessarily lead to the explanation of many mechanical details that would trench too far on our space. The essential point of the whole process is that of making a suitable alloy; and into this we need not enter, because it has been fully considered in all its practical points when the method of effecting alloys of copper, zinc, and tin, was under consideration in the chapter dealing with these metals. Indeed, the entire process of coining is merely an exceedingly refined application of most of the mechanical processes already detailed in respect to the preparation of metals for commercial purposes generally. After the alloy is cast into an ingot, it undergoes the operation of rolling, to extend its surface, and to reduce it to the required thickness for that of the coin—a thickness subsequently rectified to the exact amount required. A species of punching machine cuts out the pieces that have subsequently to undergo mill-

ing, to give the fluted edge, and the stamping of the impression from dies, &c., &c. by which the gold and silver coins of this realm are prepared for the purpose of a circulating medium.

The present mode of coining, only imperfectly outlined above, which will presently be more fully detailed, is a wonderful advance on the methods anciently employed, especially if we had included an account of the mode of weighing, which is automatic, and accurate to the last degree of mechanical ingenuity. The early specimens preserved in our museums have little or no claims as art-productions. The processes anciently adopted were evidently the most imperfect, and were probably effected by hand-labour, as any indication of machinery having been used is entirely wanting. Mr. Barlow observes, that "the hand-hammer was the only method known until the time of Henry II., of France, in whose reign the coining-mill was first invented by Antoine Burcher, a French engineer; the first money struck by a mill, or press, bearing date 1553. Like most other important inventions, however, many objections were made to it, particularly to the expense with which it was attended; and it was, accordingly, after have been in use for about thirty-two years, laid aside by Henry III., in 1585, and was not revived in that country till the year 1645, and then by Louis XIV. The press was, in the interval, introduced into England by Elizabeth, in 1562; but, as in France, it was afterwards laid aside, and the process by hammer had recourse to. In the year 1662, the mill was again put in force; and no other means have been since employed, although the machinery itself has undergone great changes, and has received various and extensive improvements."

We are indebted to the kindness of a friend for the following communication in reference to the method of coining sovereigns and half-sovereigns in the London Mint, which gives an account of the process. The description is given by a worker in the London Mint, and may, therefore, be considered as being *ex cathedrâ* in respect to the information afforded.

"The gold from the mines of California and Australia differs considerably in its quality; that from California being kind and malleable, and that from Australia crisp and brittle. This is noticeable in all the gold coin from the Australian Mint, the metal being so short and brittle, that a good 'ring' on a counter, or the force of one's teeth, would break it. This never happens with gold from California. The gold from the two countries is equally valuable. After the quartz containing the gold is removed from the mine, it is crushed by powerful machinery, and washed from all impurities. It is then brought to this country as gold-dust, and exchanged for its full value of coin by the directors of the Bank of England. When the directors of the Bank have accumulated in their cellars gold-dust to the amount of from eighty to 120 tons weight, they communicate with the Mint authorities, with a view of getting it converted into coin. It is customary to remove the gold from the Bank to the Mint in quantities of two tons at a time, melted into ingots weighing about 200 ounces each. At the Mint the gold is taken charge of by the assay-master, who, after testing every bar, gives his receipt for it according to its standard of value, pure gold being represented by twenty-four carats of value. From the assay-office the gold is taken to the melting-house, and there the pure gold is reduced in value to the English standard by adding copper with it in the proportion of one part of copper to twelve parts of gold, the English standard of gold being twenty-two carats. Plumbago crucibles are always used for melting the gold. The copper and gold alloy having been thoroughly incorporated in the crucible, is then poured out into moulds in shape very like a bar of soap, and of about the same size.

"From the melting-room the gold bars are taken to the rolling-room, and there passed through heavy rollers, turned by powerful machinery, until it is brought to a required thickness. This rolling out of the gold gives it very much the appearance of rusty hoop-iron. But in rolling out the gold in those thin long strips it is impossible to secure a uniform thickness, the sheet or strip being always thicker, as the edges are reached, than in the middle. To remedy this, the fillets are next 'dragged' between two fixed cylinders. The process of 'dragging' secures a greater regularity of thickness than 'rolling.' But even by this means it is found impossible to obtain a strictly true thickness to a plate of metal, the edges being invariably thicker than the middle. Having been reduced to the nearest possible uniformity of thickness, the plates are taken to the punching-room; and here the round pieces of gold, afterwards to be converted into sovereigns and half-sovereigns, are punched out by means of powerful machinery. But the punches used for this purpose are not all uniform in size, the punches varying according to the part of the plate on which they are to be brought to bear; the largest punch being used for the middle of the plate or fillet, and the smallest for the outsides, the largest sovereign punch being about the sixteenth of an inch greater in diameter than the smallest. Two tons weight of gold will supply about two hundred thousand sovereign pieces, the waste pieces being returned to the melting-pot, afterwards to undergo the process of melting, rolling, and dragging.

"The next process is that of turning up the edge, and 700 pieces are 'burred' up per minute. Up to this point the metal piece retains a very dirty appearance, and has rather the resemblance to rusty iron than to gold. It has also been rendered intensely hard by the various rollings, punchings, and pressings.

"The gold pieces are then put into pans, over which there are placed many covers and layers of clay, so that the air may be kept from the metal in the pot whilst it is undergoing the next process—that of softening. These pans, charged with gold pieces, and covered over with many covers and layers of clay, are then placed in a furnace, which is heated to just below the point

at which copper melts. This process, which is known as 'baking,' reduces the gold pieces to a very soft, workable condition, which condition they retain until again hardened by pressure in the die-press. Having been baked, to soften them, the pieces are next 'boiled,' to cleanse them of all impurities, and to restore them to their bright colour. To do this they are put into a copper containing water and a small quantity of acid. But this boiling process is of no effect unless the piece be dried instantly upon its being taken from the water; for just in proportion to the length of time that passes between the time of the piece of gold being taken from the water to its being thoroughly dried, so is it tarnished. The gold, is, therefore, thrown out of the copper into a heap of wood sawdust highly heated. After the piece of gold has remained a sufficient length of time in the sawdust, it is removed therefrom by means of a sieve, and presents a beautiful and bright appearance. It is also so soft that it may be doubled up by the teeth, or any other slight leverage.

"The machinery for weighing next requires notice. It may be observed that it is so beautiful and accurate in its operation, that the pieces are weighed and sorted after the rate of one every three seconds. The process of stamping is completed after the rate of seventy a minute, or less than a second to each coin. But although the coin is now completed, it has to undergo several processes before it is put into circulation. The next process is known as that of 'ringing.' Young men and lads take the coins in their hands, and, with wonderful rapidity, throw them on plates of glass, and, by the ring, pronounce them to be sound or unsound. It was but seldom that a defective coin passed undetected the notice of the 'ringers;' but still it did sometimes happen that people got coins that would not 'ring,' and, in consequence, thought they had bad coin. But this was not necessarily the case. In pouring the molten metal from the melting-pot into the mould, the air would sometimes get into the metal, and cause, what was to be seen in most metal castings, air-holes. As the bar underwent the process of rolling, punching, and pressing, this air-hole, however small it might be, was lengthened out to a great extent, and sometimes extended over a considerable space, thus causing the 'slit' that was sometimes discovered in coins even after they had been some time in circulation. The coins are next 'pounded;' that is, they are put up into lots of 1 lb. weight each, and are then tested as to their weight in the aggregate.

"The Australian alloy is precisely similar to that used at the London Mint. The fact that the Australian coinage did not wear so well as the English, was to be attributed to the want of care in 'burring' up the edge of the coin. The outer edge of an Australian coin was much shallower than that of an English coin; and the consequence was, the obverse and reverse, having little or no protection, soon presented a worn appearance, whereas the English coin was well protected. There is a very simple and very good test as to the goodness or badness of coin. If, when taking a piece of coin between the thumb and fore-finger, you find it to 'bite,' or hold to the finger and thumb, it is an excellent evidence of its goodness; but if it feel smooth and slippery, then the coin may be pronounced bad or doubtful."

At page 163 *ante*, when describing the operation of gold-beating, and noticing the thinness of the leaves produced, it was also stated that a very thin leaf of gold is to some extent transparent, allowing a kind of greenish light to pass through. Some very interesting experiments were made many years ago by Faraday the substance of which is given as follows:—

Faraday's Investigations on the Relation of Gold, &c., to Light.—These investigations formed the subject of the Bakerian Lectures for 1857. The extent of the paper, as published in the *Philosophical Transactions of the Royal Society*, forbids our entering, however, on full details of the subject. Faraday commenced by a general reference to the laws of light in regard to the undulatory theory, the cause of colour, and other points of interest in optical science. He remarks—"Conceiving it very possible that some experimental evidence of value might result from the introduction into a ray, of separate particles having great power of action on light, the particles being, at the same time very small as compared to the wave lengths, I sought among the metals for such. Gold seemed especially fitted for experiments of this nature, because of its comparative opacity amongst bodies, and yet possessing a real transparency; because of its development of colour, both in the reflected and transmitted ray; because of the state of tenuity and division which it permitted, with the preservation of its integrity as a metallic body; because of its supposed simplicity of character; and because known phenomena appeared to indicate that a mere variation in the size of its particles gave rise to a variety of resulting colours. Besides, the waves of light are so large, compared to the dimensions of the particles of gold, which in various conditions, can be subjected to a ray, that it seemed probable the particles might come into effective relations to the much smaller vibrations of the other particles; in which case, if reflection, refraction, absorption, &c., depended on such relations, there was reason to expect that these functions would change sensibly by the substitution of different-sized particles of the metal for each other. At one time I hoped that I had altered one coloured ray into another by means of gold, which would have been equivalent to a change in the number of undulations; and though I have not confirmed that result as yet, still, those I have obtained seem to me to present a useful experimental entrance into certain physical investigations respecting the nature and action of a ray of light. I do not pretend that they are of great value in their present state; but they are very suggestive, and they may save much trouble to any experimentalist inclined to pursue and extend this line of investigation."

Gold leaf was first the subject of investigation; and Faraday, with De La Rue, satisfied himself that a leaf having a thickness of $\frac{1}{278000}$th of an inch was *transparent*, and that the transmitted light was green—a singular fact, that what we usually consider to be the most opaque of bodies, really, when of a minute thickness, allows the passage of light through it more especially as the transmitted light is about complementary to the natural colour of the metal. At this rate, a leaf of such gold is only about a fifth or an eighth part of a single wave of light. By various means, chemically employed, without in any way affecting the mechanical condition of the gold, he succeeded in causing such a film to transmit far more light than it did before such treatment; but, at the same time, it reflected less. The gold lost its green colour, which, however, was restored by pressure.

Faraday next experimented with gold films with heat, pressure, chemical agents, diffused particles of gold in liquids and solids in reference to relations with light; the metallic character of divided gold; and also with other metallic films not liable to oxidation under the circumstances of the experiment. In reference to the relations of gold to polarised light (just hinted at), he found that a leaf of gold, such as we have described, produced generally the same depolarising effect as that effected by other transparent bodies. In various experiments, he found that the plane of polarisation and the plane of inclination had the same relation to each other. In all cases with gold leaf, it was found that the ray rotated when viewed by a Nichol's prism; that it required a little direct rotation of the analyser to regain the minimum light; that, short of that, red tints appeared, and, beyond it, blue or gold, these being necessarily affected in some degree by the green colour of the gold leaf. He passed the coloured rays of sun-light through various gold fluids and films, but could not perceive, when any portion of a ray passed, that it differed sensibly in colour or quality from the ray passing into the preparation. By variation of the circumstances of the rays, the same negative effects arose, and so he effected no great results, but still they were of much interest.

PLATINA, OR PLATINUM, AND ITS ASSOCIATED METALS.

Of all the metals that metallurgists and practical chemists know and treat, platinum, or platina, is certainly the most valuable for their purposes; and if we may be permitted to use a very tautological expression, we should denominate platina as the "most perfect" of all "perfect metals." With the exception of those usually associated with it, platina is the least distributed metal with which we are acquainted; and, as we shall subsequently show, it possesses properties that no other metal has.

With the exception of its mixture, or alloys, with osmium, iridium, &c. (all metals much resembling it in general character), platina is only found native. In fact, it has little affinity for any other body in nature, so far as is yet known; and is altogether an exception, in most respects, in the usual affinities, &c., of metals. Its only solvent, in a pure state, is nitro-hydrochloric acid, or *aqua regia*. In many of its qualities, except colour (which is nearly like that of silver, and from which circumstance its name, signifying "little silver," is derived), it resembles gold.

Native platina is found in veins of quartz and sienite, and in alluvial sands; and in this feature resembles gold in respect to its geological aspects; for the countries in which it is discovered are generally, but not universally, identical, as the Ural Mountains, Brazil, &c., &c. It is, perhaps, one of the most sparsely discovered of all the metals; and thus its geological position is restricted in the number of localities, although otherwise associated with gold. Native, it has a specific gravity rising from 17·5 to 19·; increased, as we shall subsequently notice, by the mechanical and other processes to which it is subjected.

Although well known to the natives of the countries in which it is found for a long time past, its discovery, so far as science is concerned, may be dated at little more than a century back; whilst our knowledge of the mode of reducing it to an available state, is of still more recent date.

Dr. Wollaston was the first to reduce the mode of working this metal to any practical purpose; and, until his discovery, platina was simply a curiosity to mineralogists or metallurgists. Being the most infusible of all commonly known metals, but yet having the property of welding like that of iron, it was still exceedingly intractable, until the sagacity of Wollaston placed in our hands methods by which this metal becomes of the greatest value to the practical chemist in chemical manufactures, especially for the distillation of sulphuric acid; and for other purposes to which we shall more particularly allude.

Dr. Wollaston was one of the most accurate experimenters in a day by no means dark in the annals of chemistry, pure or applied; for his contemporaries, in this country, were Davy, Dalton, Brande, Henry, and others, just at the time that Faraday was entering into scientific life. Although very recently, Deville, eminent by his method of cheaply producing aluminium, has introduced much more rapid processes for bringing platina into the state of an ingot, especially by means of the oxy-hydrogen blowpipe; to Wollaston belongs all the credit of not only first resolving the difficulty of reducing platina to a malleable and ductile state, but also of originating the method (still adopted) of getting it into a condition in which it may be acted on according to more modern processes.

Wollaston long kept his process secret, and deservedly amassed much money by its exercise. Although by no means avaricious in his character, he still had the shrewd sense to use science for his personal benefit; and thus got, and deserved, a rich harvest—rarely the good fortune of the experimental chemist. In the *Philosophical*

Transactions of the Royal Society, for 1829, a full account is given of the method he adopted; and, for reasons already assigned, and as an interesting matter of philosophical history, we transcribe a portion of it to these pages.

"As, from long experience, I, probably, am better acquainted with the treatment of platina, so as to render it perfectly malleable, than any other member of this society, I will endeavour to describe, as briefly as is consistent with perspicuity, the processes which I put in practice for this purpose during a series of years, without seeing any occasion to wish for further improvement.

"The usual means of giving chemical purity to this metal by solution in *aqua regia* (nitro-hydrochloric acid), and precipitation with sal-ammoniac, are known to every chemist; but I doubt whether sufficient care is usually taken to avoid dissolving the iridium contained in the ore, by dilution of the solvent. In an account which I gave in the *Philosophical Transactions* for 1804, of a new metal, rhodium, contained in crude platina, I have mentioned this precaution, but omitted to state to what degree the acids should be diluted: I now, therefore, recommend that, to every measure of the strongest muriatic (hydrochloric) acid employed, there be added an equal measure of water; and, moreover, that the nitric acid used be what is called 'single aquafortis,' as well for the sake of obtaining a purer result, as of economy in the purchase of nitric acid.

"With regard to the proportions in which the acids are used, I may say, in round numbers, that muriatic acid, equivalent to 150 (parts of) marble, together with nitric acid, equivalent to forty of marble, will take 100 of crude platina; but, in order to avoid waste of acid, and also to render the solution purer, there should be in the menstruum a redundance of 20 per cent., at least, of the ore.

"The acids should be allowed to digest (for) three or four days, with a heat which ought gradually to be raised. The solution being then poured off, should be suffered to stand until a quantity of fine pulverulent ore of iridium, suspended in the liquid, has completely subsided, and should then be mixed with forty-one parts of sal-ammoniac, dissolved in about five times their weight of water. The first precipitate which will thus be obtained, will weigh about 165 parts, and will yield about sixty-six parts of pure platina.

"As the mother-liquor will still contain about eleven parts of platina, these, with some of the other metals yet held in solution, are to be recovered by precipitation from the liquor with clean bars of iron; and the precipitate is to be re-dissolved in a proportionate quantity of *aqua regia*, similar in its composition to that previously directed to be used; but in this case, before adding sal-ammoniac, about one part, by measure, of strong muriatic acid should be mixed with thirty-two parts, by measure, of the nitro-muriatic solution, to prevent any precipitation of palladium or lead along with the ammonio-muriate of platina.

"The yellow precipitate must be well washed, in order to free it from the various impurities which are known to be contained in the complicated ore in question; and must, ultimately, be well pressed, in order to remove the last remnant of the washings. It is next to be heated, with the utmost caution, in a black-lead pot, with so low a heat as just to expel the whole of the sal-ammoniac, and to occasion the particles of platina to cohere as little as possible; for on this depends the ultimate ductility of the product,

"The gray product of platina, when turned out of the crucible, if prepared with due precaution, will be found lightly coherent, and must then be rubbed between the hands of the operator, in order to procure, by the gentlest means, as much as can be possibly obtained of metallic powder, so fine as to pass through a fine lawn sieve. The coarser parts are then to be ground in a wooden bowl with a wooden pestle, but on no account with any harder material, capable of burnishing the particles of platina, since every degree of burnishing will prevent the particles from cohering in the further stages of the process. Since the whole will require to be well washed in clean water, the operator, in the latest stages of grinding, will find his work much facilitated by the addition of water, in order to remove the finer portions as soon as they are sufficiently reduced to be suspended in it.

"Those who view this subject scientifically, should here consider, that as platina cannot be fused by the highest heat of our furnaces, and, consequently, cannot be freed like other metals from its impurities during igneous fusion by fluxes, nor be rendered homogeneous by liquefaction, the mechanical diffusion through water should here be made to answer, as far as may be, the purposes of melting, in allowing earthy matters to come to the surface by their superior lightness, and in making the solvent powers of water effect, as far as possible, the purifying powers of borax and other fluxes in removing soluble oxides.

"By repeated washing, shaking, and decanting, the finer parts of the gray powder of platina may be obtained as pure as other metals rendered so by the various processes of ordinary metallurgy; and if now poured over, and allowed to subside in a clean basin, a uniform mud or pulp will be obtained, ready for the further process of casting.

"The mould which I have used for casting is a brass barrel, six and three-quarter inches long, turned rather taper within, with a view to facilitate the extraction of the ingot to be formed, being 1·12 inch in diameter at the top, and 1·23 inch at a quarter of an inch from the bottom, and plugged at its larger end with a stopper of steel that enters the barrel to the depth of a quarter of an inch. The inside of the mould being now well greased with a little lard, and the stopper being fitted tight into the barrel by surrounding it with blotting-paper (for the paper facilitates the extraction of the stopper, and allows the escape of water during compression), the barrel is to be set upright in a

jug of water, and is itself to be filled with that fluid. It is next to be filled quite full with the mud of platina, which, subsiding to the bottom of the water, is sure to fill the barrel without cavities and with uniformity—a uniformity to be rendered perfect by subsequent pressure. In order, however, to guard effectually against cavities, the barrel may be weighed after filling it; and the actual weight of its contents being thus ascertained, may be compared with that weight of platina and water which is known, by estimate, that the barrel ought to contain. A circular piece of soft paper first, and then of woollen cloth, being laid on the surface, allow the water to pass during partial compression by the force of the hand with a wooden plug. A circular plate of copper is then placed on the top, and thus sufficient consistency is given to the contents to allow of the barrel being laid horizontally in a forcible press."

Dr. Wollaston then goes on to describe the kind of press which he used, and in which he employed a long lever, acting vertically against a horizontal rod, the latter forcing a piston into the barrel just described, and thus effecting the compression of the platina powder with great force.

"After compression, which is to be carried to the utmost limit possible, the stopper at the extremity being taken out, the cake of platina will be easily removed, owing to the conical form of the barrel; and being now so hard and firm that it may be handled without danger of breaking, it is to be placed upon a charcoal fire, and there heated to redness, in order to drive off moisture, burn off grease, and give to it a firmer degree of cohesion.

"The cake is next to be heated in a wind-furnace; and, for this purpose, is to be raised upon an earthen stand about two and a-half inches above the grate of the furnace, the stand being strewn over with a layer of clean quartzose sand, on which the cake is to be placed, standing upright on one of its ends. It is then to be covered with an inverted cylindrical pot of the most refractory crucible ware, resting at its open end upon the layer of sand; and care is to be taken that the sides of the pot do not touch the cake.

"To prevent the blistering of the platina by heat, which is the usual defect of this metal in its manufactured state, it is essential to expose the cake to the utmost heat that a wind-furnace can be made to receive (produce), more intense than the platina can well be required to bear under any subsequent treatment, so that all impurities may be totally driven off, which any lower temperature might otherwise render volatile. The furnace is to be fed with Staffordshire coke; and the action of the fire is to be continued for about twenty minutes from the time of lighting it, a breathing (?) heat being maintained during the last four or five minutes.

"The cake is now to be removed from the furnace, and, being placed upright upon an anvil, is to be struck while hot with a heavy hammer, so as, at one beating, effectually to close the metal. If, in this process of forging, the cylinder should become bent, it should on no account be hammered on the side, by which treatment it would be cracked irremediably; but must be straightened by blows upon the extremities, dexterously directed, so as to reduce to a straight line the parts which project.

"The work of the operator is now so far complete, that the ingot of platina may be reduced by the processes of beating and forging, like that of any other metal, to any form that may be required. After forging the ingot it is to be cleaned from the ferruginous scales, which its surface is apt to contract in the fire, by smearing over its surface with a moistened mixture of equal parts, by measure, of crystalline borax and common salt of tartar, which, when in fusion, is a ready solvent of such impurities, and then exposing it upon a platina tray, under an inverted pot, to the heat of a wind-furnace. The ingot, on being taken out of the furnace, is immediately to be plunged into dilute sulphuric acid, which, in the course of a few hours, will entirely dissolve the flux adhering to the surface. The ingot may then be flattened into the leaf (foil), drawn into wire, or submitted to any processes of which the most ductile metals are capable.

"The perfection of the methods above described for giving to platina complete malleability, will best be estimated by comparing the metal thus obtained, in respect to its specific gravity, with platina that has undergone complete fusion; and by comparing it, in respect of its tenacity, with other metals possessing that quality in the greatest perfection.

"The specific gravity of platina drawn into fine wire from a button, which had been completely fused by the late Dr. E. D. Clarke, with an oxy-hydrogen blowpipe, I found to be 21·16. The aggregate specific gravity of the cake of metallic mud, when first introduced into the barrel, exclusive of moisture, is about 4·3; when taken from the press, is about 10·0; that to which the cake fully contracted, on being taken out of the wind-furnace before forging, is from 17 to 17·7. The mean specific gravity of the platina, after forging, is about 21·25, although that of some rods, after being drawn, is 21·4; but that of fine platina wire, determined by comparing the weight of a given length of it with the weight of an equal length of gold wire drawn through the same hole, I find to be 21·5, which is the maximum specific gravity that we can expect to be given to platina.

"The mean tenacity, determined by the weight required to break them, of two fine platina wires, the one of $\frac{1}{3000}$th, and the other of $\frac{1}{3850}$th of an inch in diameter, reduced to the standard of a wire $\frac{1}{10}$th of an inch in diameter, I found to be 409 pounds; and the mean tenacity of eleven wires, beginning with $\frac{1}{4500}$th, and ending with $\frac{1}{25000}$th of an inch, reduced to the former standard, I found to be 589 pounds; the maximum of these eleven cases being 645 pounds, and the minimum 480 pounds. The coarsest and the finest wire which I tried, present exceptions; since a wire of $\frac{1}{1500}$th of an inch gave 290 pounds, and a wire of $\frac{1}{30000}$th of an inch,

190 pounds. If we take 590 pounds, as determined by eleven consecutive trials, to be the measure of the tenacity of the platina prepared by the processes that have been described, and consider that the tenacity of gold wire, reduced to the same standard (the tenth of an inch), is about 500, and that of iron wire 600, we shall have full reason to be satisfied with the processes here detailed, by which platina has been rendered malleable."

The preceding account is of deep practical and philosophical interest, and amply exhibits the care, as an experimenter, that Wollaston was so noted for possessing. Perhaps no one in the history of chemical science, with the exception of Faraday, has been so highly esteemed for all those qualities which characterise the philosopher; and few men have done more for pure and applied chemistry than those two eminent individuals.

At the present day, the oxy-hydrogen blowpipe has been applied, on a large scale, for the purpose of bringing platina into a solid and condensed condition by fusion. Most of our readers will be aware, that when hydrogen and oxygen gases are burned together, by means of a proper arrangement, the most intense heat that can be produced artificially is obtained. In the Exhibition of 1862, Messrs. Johnson and Mathey, of Hatton Garden, London, the largest platina manufacturers in Europe, showed an ingot which weighed between 3,000 and 4,000 ounces. At the same time, specimens of iridium, also melted into an ingot, and an alloy of iridium and osmium, were also exhibited by the same firm.

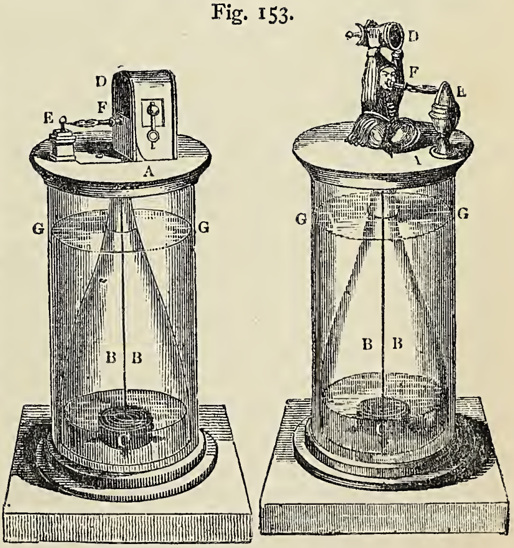
The use of platina in the arts is, of course, comparatively limited. It has been used as coin in Russia; and, in this country, is occasionally converted into snuff and other presentation boxes; but, except in manufacturing or scientific circles, it is rarely seen.

Its chief use in manufactures is that of distilling sulphuric acid. As this compound is obtained from the leaden chamber in which it is produced, its specific gravity and strength are much below that required in certain chemical manufactures, as soda-making, bleaching, &c. If it were boiled in earthenware vessels it would speedily attack them; and in glass vessels the process would be extremely dangerous, owing to a peculiar violence that occurs in giving off its vapour. Boiling sulphuric acid attacks all the ordinary metals with great violence; gold and platina alone can resist its action. But as gold is too expensive, platina has been had recourse to; and hence the makers of sulphuric acid have stills made of it. Some of these are of great value. Messrs. Tennant, of Glasgow, have some worth over £3,000 each; but the first cost may be considered as the last, except that arising from occasional repairs, as, externally, every care is taken to prevent injury to so costly a vessel. One of the stills made by Messrs. Johnson and Co., already named, was shown at the Exhibition of 1862; and the construction was such as to permit of the distillation of three tons of the acid in the course of twenty-four hours. The joints are made by means of the oxy-hydrogen blowpipe, after the method of autogenous soldering, by which the superficial fusion of the metal makes a joint, or by using a kind of solder containing gold and platina.

A curious and fraudulent use of platina was discovered a short time ago, which exhibited considerable and, for some time, no doubt, successful ingenuity, although turned to a bad purpose. Platina and gold have a not very greatly different specific gravity; and hence, in an equal mass of each, if tested by weight alone, the substitution of platina for gold might almost pass unnoticed. This fact was adopted by some evil-disposed persons to debase sovereigns: the coins were cut in half, and a thin plate of platina introduced, which was soldered intermediately between the halves, as much gold being filed away as sufficed to still leave the sovereign its proper weight. This fraud was, of course, most difficult of detection, on account of the skilled manner in which it was executed, and from the fact that the weight and specific gravity of the debased coin did not perceptibly differ from that of a genuine one. Chemical means were equally ineffectual for the detection of the fraud, which must evidently have been perpetrated by one or more persons versed in physical science.

A limited use of platina, of some interest, is that in which it is employed to afford an instantaneous light. It is easily reduced to a black powder by solution and precipitation, already explained; and in that form, as well as in foil, has such a power of uniting oxygen and hydrogen gases as to cause an explosive combustion if the two be mixed together, owing to the great amount of heat thus generated. Such an arrangement is adopted in the lamp of Dobereiner, the name of the inventor. The annexed cuts illustrate this; and the letters have the

Fig. 153.



same signification in each. A is a plate or cover that fits air-tight on a glass cylinder. Inside this is a bell, which has communication at the

bottom with a liquid that rests between G G and B B, but which is separated from the inside of B B, except at the bottom of the bell, which is open. Inside B B is a piece of zinc suspended by a wire. A little dilute sulphuric acid is first introduced into the glass cylinder by removing the cap A, which is again replaced air-tight; and, by opening the top at F, communication is permitted with the air. As soon as the acid touches the zinc it produces hydrogen, from the decomposition of the water; and this is allowed to escape for some time, because mixed with air. The tap at F is then closed, and gas continues to generate in B B; but, at the same time, forces the acid water out of it into the space between B B and G G, as seen in the water-level in the cuts. Now, by thus forcing out the acid liquid, the zinc plate, C, is freed from it, and the production of gas ceases. If a light be now required, it is only needful that a tap should be opened, when the hydrogen gas will escape, and, impinging on a little ball of spongy platina at E, will catch fire. Meanwhile the escape of gas causes a diminution of pressure within the glass bell, B B, consequently the acid water descends, and again reaches C, the zinc plate, when more hydrogen will be produced. As soon as the tap at F is closed, the acid is again driven out of B B, but sufficient hydrogen is left in it to re-kindle a light when required. In the right-hand cut, at D, a cap is shown, which is intended to cover the platinum ball, E, when not in use; as dust, atmospheric air, &c., impede or diminish its action, if allowed to get continued access to it. The whole instrument is a most ingenious adaptation of physical and chemical science.

Some years ago it was proposed to employ spongy platina for the conversion of spirits into vinegar, which it readily effects by its oxidating action on the hydrogen and carbon of the spirit, when properly applied in the spongy condition. Practically, however, this method has never been adopted, for fiscal and other reasons; and it is now only seen in operation at the lecture-table for illustrating the facts already stated, and also to show how platina, either as sponge or foil, can produce a continuous light by combining oxygen and hydrogen, either in the manner already described, or by a coil of wire fixed over the wick of a spirit-lamp. The wire, when once heated red-hot, will continue the combustion although the wick be removed, affording also an amount of light. A modification of the same curious experiment is that of inserting a red-hot coil of platinum wire in a glass of ether, but not touching the fluid; the wire will yet retain a red heat, and continue glowing until all the ether is consumed.

In the laboratory platina is of the highest value to the practical chemist. It serves admirably for making crucibles, trays, and other vessels that will resist the action of most chemicals. This is the reason it has been employed in the form of a worm for boiling vinegar in making pickles. In the old method the vinegar was frequently boiled in copper vessels; and many cases of poisoning resulted from this pernicious practice. But by sending steam through a platina worm, immersed in the vinegar held in a wooden vessel, the metal being unacted on by the acetic acid present, entirely prevents any possible cause of danger from metallic solution.

There are numerous points, in chemical and electrical science, that might be discussed in reference to this metal; but as they are of purely philosophical interest, a bare mention of a few not yet named must suffice. In electricity, platina is invaluable as the negative plate of Grove's nitric acid battery—the most powerful electromotive arrangement we possess. From its not being acted on by most chemicals, it also forms excellent electrodes, or poles for electro-chemical decomposition. Its powder coats the silver or negative plate of Smee's battery.

The power it has of causing the evolution of heat and light when in the form of sponge, or black powder, is one of the most notable properties of platina; but not alone possessed by that metal, for palladium can absorb some gases with an astonishing avidity. It is generally considered that this curious property is due to the condensation of the gases, oxygen and hydrogen, on its surface; and some very curious results have been arrived at by several experimenters, including Faraday, Graham, Deville, and others.

The phenomena of dialysis seem intimately connected with this property. By this is meant the power which certain membranes have of separating fluids by pure spontaneous mechanical action. Dr. Graham, Master of the Mint, was one of the first to effect dialysis, or analysis by diffusion. The principles of this singular result may be described as follows:—If some solutions are placed in a kind of drum, formed of membranous matter, and this be placed in another vessel containing distilled water, the contents of the drum or dialyser are separated. Then, supposing the contents of the stomach, containing albuminous and other matters, with arsenic, or other metallic substance, be thus placed in a dialyser, the soluble metallic substances will pass through the membrane, and be found dissolved in the distilled water, whilst the albuminous, or other animal matter, will be retained in the dialyser. By such means, bodies of all kinds, of different diffusive power in a fluid, may be completely separated, without the slightest introduction of any chemical agent, by way of precipitation, or the ordinary method of chemical analysis. Generally, we may add, that the effect of dialysis on fluids is that of separating crystallisable and soluble substances from colloid or gelatinous, whether the bodies that are colloidal be animal, or such gelatinous precipitates as those of silica and alumina.

This curious result was noticed first, as far as we are aware, in the peculiar action called, at the time, respectively endosmose and exosmose, relating to the inward or outward motion of fluids of different densities, through septa or division of animal membrane, as bladder, plaster of Paris, brown paper, &c., &c., and particularly in the action of such divisions in Daniell's constant battery, in which sulphate of copper in

solution is placed on one side of a porous diaphragm, and dilute sulphuric acid on the other. But gradually the principle was found to be more universal; and Dr. Graham showed that, through such materials, a light gas, such as hydrogen, may be made to descend, and a heavy one, like carbonic acid, to ascend—contrary to all the then understood laws of gravity, and the supposed physical character of gases.

Still more recently the subject has been extended, and it is found that metallic bodies, especially platina, are permeable to gaseous bodies: in other words, the lightest body in nature can permeate the most dense. One, amongst many communications made public on this interesting fact, will be found in a paper read before the Royal Society, towards the close of 1866, "On the Absorption and Dialytic Separation of Gases; first, by Colloid Septa; and secondly, by Metallic Septa, at a red heat"—of which the following is a summary:—A thin film of caoutchouc, such as is furnished by varnished silk, or the transparent little balloons of india-rubber, has no porosity, and is really impervious to air or gas. But the same film is capable of liquefying the individual gases of which air is composed; while oxygen and nitrogen, in the liquid form, are capable of penetrating the substance of the membrane (as ether or naphtha does), and then evaporating into a vacuum, and appearing as gases. The permeating power of atmospheric air becomes more interesting from the fact that the gases are unequally absorbed and condensed by the india-rubber (oxygen being absorbed two-and-a-half times more abundantly than nitrogen), and they permeate through the rubber in the same proportion. Hence the plan may be used as a dialytic sieve for atmospheric air, since it evolves 41·6 per cent. of oxygen, instead of only 20·8 per cent., present in air. The septum, in fact, keeps back one-half of the nitrogen, and allows the other half to pass through, with all the oxygen. The dyalised air rekindles wood just smouldering red, and is, in fact, exactly intermediate between air and pure oxygen gas, in relation to combustion. One side of the rubber film must be freely exposed to the atmosphere, and the other side be under the influence of a vacuum at the same time. The vacuum may be established within a bag of varnished silk, or in a little balloon, the sides being prevented from collapsing by a thickness of felted carpeting, or filling the cavity with sawdust. For procuring a vacuum in such experiments, the air-exhauster of Dr. Hermann Sprengel is admirably adapted. It possesses the advantage that the gas drawn from the vacuum can be delivered by the instrument into a gas-receiver placed over water or mercury. In Professor Graham's opinion, the surprising penetration of platina and iron tubes by hydrogen gas (discovered by MM. H. Sainte-Claire Deville and Troost), is dependent upon a power in the metals to liquefy and absorb hydrogen, possibly in the character of a metallic vapour. Platina, in the form of wire or plate, at a low red heat, takes up 3·8 volumes of hydrogen, measured cold. Palladium foil, from the hammered metal, condenses the extraordinary quantity of 643, its volume of hydrogen, at a temperature under 212° Fah. The same metal has not the slightest absorbent power for either oxygen or nitrogen; hence Dr. Graham considers that a peculiar dialytic action may reside in certain metallic septa, enabling them to separate hydrogen from other gases. In the form of sponge, platina absorbs 1·48 its volume of hydrogen; and palladium, 90 volumes. The former metal, in the condition of platina black, takes up several hundred volumes of the same gas. The assumed liquefaction of hydrogen, under such circumstances, appears to be the primary condition of its oxidation at a low temperature. A repellant property, possessed by gaseous molecules, appears to resist chemical combination, as well as establishing a limit to their power to enter the minute pores of solid bodies.

This statement of the results of experiments, and the speculations or theories founded on them, not coming from one given to speculative habits, but rather characterised by most philosophical qualities, are of the greatest interest, not only to the man of science, but to all who take even a general interest in the operations of nature. They seem to lead us to an entirely new view of the constitution of solid bodies, and may, perchance, in the course of time, result in a great modification in, if not an entire revolution of, those "principles" on which, hitherto, natural philosophy and chemistry have been based.

The general chemical relations of platina have, to a certain extent, been incidentally mentioned in the account of its manufacture according to the method of Wollaston. It forms oxides with oxygen, one of which has sufficient characters of combination as to have obtained for it the term of platinic acid; and it thus resembles gold, which, under certain circumstances, affords auric acid. Platina also combines with sulphur to form a sulphide; and, indirectly, from this, by the oxidating action of nitric acid, a sulphate of platinum may be obtained. The chlorides are its most important combinations: of these are two, formed directly by the union of chlorine with platinum—the protochloride and bichloride. But platina is also capable of forming double salts. Thus, with potassium, it forms the double chloride of platina and potassium, which is a yellow crystalline body; and the only method of estimating potass in analysis, with any degree of exactness, is by forming this salt. With sodium, platina produces the double chloride of the two metals, distinguished from the preceding by its solubility. With ammonium, the hypothetical base of ammonia, platina affords a double salt; and in this form it is that the nitrogen, contained in animal and vegetable bodies submitted to organic analysis, is estimated quantitatively. There are other chemical combinations of platina, but they possess no general interest in a practical point of view. With ammonia, the binoxide of platina forms a fulminating compound; and some curious results are produced by the agency of

that alkali on the protoxide and protochloride of platinum, the compounds having considerable analogy, in their constitution, to those of an organic nature—a question of great scientific interest; but one on the discussion of which we cannot enter.

Platina is, by its peculiar chemical qualities, easily separated, in analytical investigations, from most other bodies, the only difficulties that occur of importance, being the presence of metals frequently associated with, and greatly resembling it in certain properties. We refer to iridium, rhodium, osmium, &c., of which we shall speak in fuller detail presently. Platina is only soluble in nitro-hydrochloric acid amongst acids; and from this it is precipitated by sal-ammoniac, as previously noticed, together with a little alcohol. The precipitate should be washed by alcohol; and, on ignition, the platina is obtained in the metallic state, in which condition it is weighed. It may be thus separated from iron, manganese, cobalt, copper, mercury, and all metallic chlorides soluble in alcohol; and should any traces of them be found they may be removed by first reducing the platina from the double chloride of itself and ammonium, and then digesting the mass *separately*, with either nitric or hydrochloric acid. If these were used together, of course the platina would also be dissolved. With hydrosulphuric acid (sulphuretted hydrogen), platina affords a black sulphide insoluble in water, and easily reduced by heat. Hydrosulphate of ammonia also precipitates a black sulphide; but this is soluble in excess of the precipitant. As already intimated, salts of potassium and ammonium precipitate, respectively, the double chlorides of the metal with potassium and ammonium. With protochloride of tin, a red stannate of platina and tin is afforded.

Metals associated with Platina.—These are iridium, osmium, ruthenium, palladium, and rhodium, all far more scarce than any of the metals yet described; and, with the exception of palladium, of but little application in the arts.

Iridium is found, alloyed with platina, in many of the ores of the latter, as already noticed incidentally at p. 181, *ante*, when the process of Dr. Wollaston, for preparing platina, was described; and, at the same time, the mode of separating it from that metal was in part detailed. It also occurs in *Osmiridium*, an alloy of iridium and osmium, found in isolated crystals and grains, with gold and platina, in South America, the Ural Mountains, Borneo, &c. It is, perhaps, the most intractable of all metals, being unacted on by any acid; for, as noticed at the page just referred to, it is precipitated from platina, in solution of the ores of that metal, even in nitro-hydrochloric acid. It is separated with difficulty from osmium; and, when obtained in the metallic form, resembles, in some respects, a similar condition of platina previously described. It has been melted by the oxy-hydrogen blowpipe into an ingot. Its specific gravity is about that of platina, and it is one of the hardest of the metals; hence, although far dearer in its present price than gold, it has been used as an alloy with osmium for tipping the points of steel pens.

Osmium derives its name from the peculiar smell of its acid, as iridium is named from the variety of colours it assumes by chemical combination. The source of osmium is the alloy previously named, as it is one also of iridium. Osmium has a white colour; a specific gravity of about 10; is highly infusible, brittle, but slightly malleable. It has no economic uses but that already pointed out as an alloy of iridium.

Rhodium is a metal obtained from platina ores, after the platina and palladium present have been removed. It is brittle, hard, and infusible; exceedingly intractable with any ordinary chemical agent; specific gravity about 11·0; and its only use has been to afford hard points for steel pens, mathematical instruments, and similar objects, the ends of which are required to resist wear. Ruthenium may be briefly mentioned as another metal associated with platinum; exceedingly rare, and of no application in the arts, &c. It so much resembles iridium as to have been long confounded with that metal; but its specific gravity is much less, not exceeding 8·5.

Palladium is the only metal of any commercial importance associated with platinum. It occurs in rolled grains with that metal; and, as particles, imbedded in, and combined with, gold in the Hartz Mountains, Brazil, &c. When obtained from platina ores on solution of these in nitro-hydrochloric acid, the platina having been removed, the palladium is precipitated by cyanide of mercury, the solution having been previously neutralised by carbonate of soda, to remove excess of acid. The cyanide of palladium thus afforded, on being exposed to a strong heat, affords palladium in a powder, which is converted into a metallic ingot, after the methods already described as followed for reducing platinum to that condition. It has a silver-gray colour; difficult of fusion—much resembling platina in that respect; may be, in a measure, welded; is malleable, ductile, and comparatively soft. Its specific gravity is from 11·5 to 11·8. It has the advantage of being unacted on, at ordinary temperatures, by either air or moisture; and from this circumstance it has had several applications in the arts, &c.; as for constructing artificial palates for dentistry, when its malleability and softness make it a cheap substitute for gold; also for making beams for chemical balances, scales for mathematical instruments, and for other purposes in which its physical and chemical properties render it advantageous. It is acted on by nitric acid; and, as already noticed, is soluble in nitro-hydrochloric acid. One of its chief chemical characteristics is its great affinity for cyanogen.

Some very interesting analogies present themselves frequently in the physical and chemical character of metals; and in none more so than the group just examined, more especially as they are all obtained together from nearly one ore. But many of the metals may thus be grouped together by what we may term natural

affinities. For example, potassium, sodium, and the hypothetical ammonium, are all characterised in their oxides by eminently possessing alkaline properties, whilst their chemical combinations with acids, &c., are frequently of striking analogy. Potassium and sodium much resemble each other in their metallic condition and properties, whether in respect to inflammability, specific gravity, or tenacity. Another such group may be found in barium, strontium, calcium, and magnesium—all metals forming earths or oxides; and their metallic character is also very closely allied. Amongst the more common metals, iron, nickel, cobalt, chromium, and manganese, may similarly be grouped; the three first especially, as possessing magnetic properties not evidenced by any of the other metals. Gold and silver we have already seen to be much connected by similarity in both physical and chemical properties; and in part, mercury, but certainly platinum, may be associated with them. Yet the relations of platinum are more connected with the metal iridium, for reasons already assigned.

Now these analogies, or similarity of qualities, are highly suggestive; but they are aided still more by another circumstance, which arises from what is called, in chemical science, *isomorphism;* by which is meant that one body can replace another in a combination capable of crystallisation, without altering the characteristic form to which such a crystal is assigned according to the system of crystallography. Thus, for example, iron is isomorphous with aluminium; that is, their sesquioxides can replace each other: the same may be said of chromium. One of the best instances of the kind is that found in what are familiarly known as alums, a form of which is of great use in many of the arts, domestic life, &c. Thus there may be a potass-alum, an iron-alum, and a chrome-alum, besides many others we need not particularise. Copper and iron, again, are isomorphous; and, if their sulphates get mixed together in solution, they are undistinguishable.

But the question, although of deep interest, is of far too extensive a character to be here properly discussed. One matter seems certain: it is, that whilst we increase the number of elementary bodies by new discoveries, we constantly perceive fresh relations to arise, by which some connecting link may be discovered that lessens an, at first, apparent dissimilarity. Possibly, after all that has been said of alchemy and the dreams of alchemists, their hope of being able to convert all the metals into fewer, or even one, may yet be realised. This fact is certain—that it is impossible for us to accurately define what a metal really is. If specific gravity be a test, then potassium and sodium should be left out of the list; and, for similar reasons, they, with mercury, lead, &c., must be excluded if hardness and tenacity be too strictly enforced as a condition. But, going beyond the range of metallic bodies, we have but recently pointed out the close affinity which seems to subsist—not chemically, but mechanically—between certain metals and gases. When describing the peculiarities of dialysis in relation to metallic septa, at p. 184, *ante*, it was shown that platina and palladium had great attraction for hydrogen and oxygen, but especially the former. Now hydrogen and platinum stand at the two extremes of our known bodies in every possible respect. Hydrogen is the lightest, and platinum, perhaps, the heaviest body in nature: one is a permanent gas, that has never been solidified nor rendered liquid; whilst the other is the most stable substance of all solid bodies, resisting the action of heat to the utmost, and that of most chemical agencies.

It will be thus seen what a wide field lies open for the physicist and chemist, in respect to gaining a more complete knowledge of the actual characteristics of all, but especially metallic, bodies. It is true that we may properly boast of the great advances which science has made during the present century; but the more we advance, the more there seems to be done. At the same time, it is encouraging to know that the means of progress, whether in respect to pursuing philosophical investigation, or the applications they may give rise to, were never more ample than at the present day. The great improvements in, and the reduced price of, apparatus necessary for such investigations; the spread of scientific knowledge, attended with an increased and constantly increasing number of its followers, scattered throughout the world, exploring new fields of research in the laboratory and the land; with many other concomitant circumstances—all tend to add rapidly to our knowledge of facts, on which we may build new theories, that may, in their turn, by generalisation, tend to further progress in science.

The preceding pages have been exclusively devoted to the consideration of such matters as appertain to coal and metal-mining generally; to the smelting and reduction of the ores of metals that are in most constant use in daily life, separately or alloyed, and in a manufactured state, as employed in the construction of machinery, and various objects far too numerous to mention.

The consideration of coal and metals in most common use was chosen as first in order, because of the more extended space which their importance, whether in quantity of production or intrinsic value, demanded. As already pointed out, some of them may be considered indigenous and proper to our island; for our coal, and the metals iron, copper, tin, and lead, are amongst the greatest items of home production and export. The metals that yet remain to be described are each important in their special aim; but the amount of their production bears no comparison with those above named.

Generally, the mining for them, and their reduction, are carried on in a similar manner to the preceding; and hence an occasional reference to what has been before remarked on such matters will be sufficient for our purpose. We shall therefore assume that our readers have sufficiently acquainted themselves with what has been advanced on such subjects, and thus much space will be saved.

METALS OF LIMITED USE IN THE ARTS, Etc.

The metals already described at considerable length have great importance in relation to the arts, manufactures, social requirements, and other circumstances ; and hence a large amount of space has been devoted to their description ; so that, as far as the limits of this work permit, all the leading features of interest connected with each have been considered. We next pass on briefly to detail the rest of the group of metals of far less general application, although frequently of great value for special purposes, and which, consequently, are procured and produced in comparatively small quantities.

Amongst such, we may first instance nickel, cobalt, manganese, chromium, bismuth, antimony, arsenic, and cadmium. Each of these, with the exception of cadmium, has some valuable application, either in alloy or in chemical combination with non-metallic bodies; but, singular to say, not one of them is employed, independently or solely as a metal, for any purpose whatever. Nickel is too infusible ; cobalt too rare ; manganese too oxidisable ; chromium generally unsuitable ; bismuth and antimony too crystalline and brittle; and arsenic, like chromium, valueless—for use as metals proper.

If, however, we take the alloys producible by some, and the chemical compounds of others, we shall find that each has an extended circle of influence on the arts and manufactures. Nickel, bismuth, and antimony enter into various combinations with copper, tin, and lead, in the production of pewter, German silver, printing-type, Britannia metal, and several other alloys, either in pairs, or in a larger number of constituents in each. Chromium is of the greatest importance in connection with dyeing, calico-printing, and the production of pigments, although valueless as a metal ; for, combined with oxygen, it produces chromic acid, so much used to afford bichromate of potass, that, with the acetate of lead, yields rich and permanent yellows to orange for the dyer and painter ; and the oxides of this metal are of much use in glass-staining. Manganese, as a metal much resembling iron, but so unstable, owing to its attraction for oxygen, as not to be capable of being exposed to the air, is invaluable in the form of black oxide ; for by it the bleacher obtains his chlorine and chloride of lime ; the calico-printer, some useful shades of colour ; the glass manufacturer, a most necessary oxidating agent, and a stain for glass ; besides affording materials for manufacturing a most effective disinfecting fluid, and in producing steel. Arsenic, again, has many valuable applications: added to lead, it hardens it for the manufacture of shot ; and has a similar effect when added to some other metals : as a colouring agent, by union with copper, it affords a fine green pigment, and is in other ways utilised, as a sheep-wash, and steep for wheat, in medicine, &c. We thus see, that although these metals are useless as metals simply, they are not without their value.

But, with these, others must be grouped, because, although of more limited use, some of them have important applications. Sir Humphry Davy could have little imagined, that when he discovered potassium and sodium—in his day very interesting, but rare chemical curiosities—one of them, sodium, should become instrumental in the production of another metal in quantities—aluminium, that was destined to play a most important part in the arts and manufactures; or that it should also be the material for producing magnesium in quantities that now render it a regular article of metal sale, although its uses are limited to that of producing intense actinic light for photographic and illuminating purposes.

It is thus that we often find, in science, researches carried on for purely philosophical purposes, that eventually rise into great importance by subsequent applications at first not dreamt of. The results we here refer to have arisen from the discoveries of science, amplified, not in the laboratory alone, but by the intelligence of scientific men largely engaged in chemical manufactures, who, uniting knowledge, enterprise, and capital, whilst securing a rich pecuniary reward, at the same time confer lasting benefit on society at large ; for whatever increases the raw material that man has at his disposal, opens out new paths of industry, extended occupation for the unemployed, and consequent relief from the burden of supporting such persons by the industrious members of society, besides, in many cases, adding new sources for the exercise of taste and refinement in regard to art-productions.

Of still less use, and much rarer than either potassium or sodium, or the two metals aluminium and magnesium (just referred to), are those obtained from other earths, as baryta, strontia, and lime, affording, respectively, barium, strontium, and calcium. So far as we know the characters of these, they much resemble aluminium ; but, at present, they have only been produced in such small quantities, that even many practical chemists, well acquainted with their properties, have not possessed, or perhaps even seen them. But we are not aware that either of them is characterised by any quality that would prevent their general use for some purpose. In respect to calcium, the metal of lime, its abundance in the British isles alone is enormous. Taking the chalk strata of Kent and adjacent counties, crossing north-eastwards from the English Channel to the Yorkshire coast, lies one immense bed of chalk, every 100 pounds of which contain no less than forty pounds of calcium, a metal much resembling silver and the aluminium just alluded to ; chalk being composed, in every one hundred parts, of—

Calcium	40
Oxygen, united with it .	16
Carbonic acid	44
	100

But, besides this immense deposit of metal in an ore state in chalk, we must also refer to

mountain limestone, which is chiefly composed of chalk mixed with magnesia, &c. This rock forms the greatest proportion of the "rocks" of these islands; and is spread from the midland counties of England, far into Scotland, and is equally abundant in Ireland. It is with this strata that our most valuable ores of other metals, and the coal-measures, are associated: yet, after all the valuable products of coal, iron, lead, &c., that we have succeeded in extracting from such beds, what we now deal with as waste, except for burning into lime, or as a flux for the iron-smelter, contains an amount of metal which, compared in quantity present with such as have just been named, may well be illustrated by the statement that it is as a mountain to a mole-hill, for it is literally, not figuratively, the case. It will be thus seen that, although we may have made great advances in extracting metals from their ores of recent years, we have, after all, barely begun the work, and that fabulous sources of riches in the country still lie untouched.

The remarks made in regard to calcium, are equally applicable to barium and strontium, both of which are abundant in this country as sulphates and carbonates: and, in respect to the possible utilisation of any or all of these as metals, we need not despair if we bear in mind how many centuries the manufacture of iron from the ore was, practically or comparatively, unknown throughout every civilised country. In the early part of our remarks on the smelting of iron, we pointed out this fact, not only in relation to this, but to other countries in Europe and Asia. Indeed, whilst iron is the most abundant of all metals, it has been, until very recently, but triflingly produced from its ores, simply because a scientific mode of their treatment was unknown. Indeed, not forty years have elapsed since the Cleveland district of our own country (so fully described in our previous pages as the most important iron-producing ore of our island), was not only neglected, but it was considered that the smelting of the ore was all but impossible. From such instances we may therefore hope, that, at some future day, our chalk, limestone, and other earth deposits, may not only be valued for the minerals they enclose mechanically, but also for those which really, in part, form their chemical constitution.

There is another class of metals to which reference must now be made, the members of which are at present with difficulty grouped: all of them are rare; some barely known; and few applied to any useful purpose. They, therefore, properly come last in consideration amongst metals of limited use. They seem, to a large extent, isolated from all the rest, and from each other; but this may certainly arise from the fact that their qualities have been but little investigated, the opportunity for so doing being, in respect to many of them, hardly attainable, owing to the infrequency of the occurrence of their ores.

Omitting, in this category, the metals that have already been dealt with as associated with platinum, and much resembling it in properties, as palladium, rhodium, iridium, &c. (see *ante*, p. 186), they are—uranium, tungsten, molybdenum, vanadium, tellurium, tantalum or columbium, niobium, pelopium, ilmenium, cœsium, thallium, rubidium, and indium.

Of the whole of this long list we can only reckon two as of the least commercial importance—uranium and tungsten—the first being used for glass-staining, enamel, and porcelain-painting; and the latter has been adopted as tungstate of soda, to render linen, &c., incombustible, or perhaps, more correctly, uninflammable. It is by no means certain that tellurium quite deserves to be ranked with the metals, for most of its analogies point out its apparently more proper connection with sulphur and selenium—bodies that have not, so far as is at present known, any but a remote claim to be considered of a metallic nature.

Four of the above named—cœsium, thallium, rubidium, and indium—form, in their discovery, an epoch in physical and chemical science. Long as it has been known that all metals produce a more or less coloured flame when submitted to the powerful heat of the disruptive discharge of the voltaic battery, and by which such splendid effects of coloured light are produced; and also that many of them will tinge ordinary flame, with a special colour for each—as yellow with sodium, green with barium, red with strontium, and so on—it was not known that each metal has its own colour-place in the prismatic spectrum, produced when light is decomposed by means of a flint-glass prism. It was found, by Fraunhofer, that sun and other light is characterised by certain lines, each having a definite position in the spectrum corresponding to the origin of that light; but it is only within the last few years it has been discovered that the light produced by the combustion of each metal has a place or band, so distinctive in its physical qualities in the spectrum, as to enable us to state, with remarkable precision, the presence of any such metal in flame, &c., although but far less than the millionth part of a grain may be recognised.

So minute are the proportions in which thallium, cœsium, &c., exist, as far as we yet know, in nature, that they entirely escaped discovery until this new agent of spectrum or spectral analysis became adopted. It is true that, even yet, supposing that their qualities rendered them eligible, they have been put to no practical use, for they have only been obtained in minute quantity. Still, as before observed, they are of deep interest, from the circumstances under which they were first found; and we cannot help expressing the opinion that Bunsen and Kirchoff, who first thus applied the spectrum, deserve an equal rank with Davy, who was the earliest to produce, by electro-chemical decomposition, the metals potassium, sodium, &c. In both cases the discoveries are characterised by a new application of old known forces to analytical purposes—light in the case of Bunsen, and electricity in that of Davy.

From the tenor of these remarks, it is evident that all the metals we have placed in the last cate-

gory, may be dismissed with the brief notice already given of them, as they have no commercial applications nor metallurgical interest. We shall, therefore, devote our remaining space to consider chiefly nickel, cobalt, manganese, chromium, bismuth, antimony, arsenic, and cadmium—the latter being of interest only as associated with zinc. To a certain extent, we shall see relations existing amongst them and some of the metals already described, not only because they are occasionally alloyed with the latter, but also on account of the properties common to each.

Nickel. — In many respects this metal resembles iron. Its specific gravity varies from 8·25 to 8·8 ; it is highly infusible—in fact, almost equally so with wrought-iron ; and is said to be both malleable and ductile : but of these two qualities, after many interested inquiries, and a desire to avail ourselves of the fact, we can only express great doubt ; at least, we have failed to procure it in any form that would justify such a statement, despite inquiring at every leading metallurgist and practical chemist in London.

Like iron, it has magnetic properties ; so much so, indeed, that it may be substituted for that metal in making mariners' compasses, &c. It is capable of receiving a high polish ; and some specimens that we have obtained by electro-deposition, have retained their polish for upwards of a year with scarcely a sign of tarnish. Its chief use in the arts is that of forming a constituent of German silver. An article is also often offered in trade, called "nickel-silver," which, from the property of retaining a polish without oxidation (one that nickel possesses, as just explained), is peculiarly suitable for that purpose.

A singular fact is discovered in relation to nickel. It is, that whilst terrestrial iron never contains it, or at least, if it do, to an extent not appreciable by ordinary means of chemical analysis, nickel is always associated with iron in meteorites containing the latter metal.

The ores of the metal are numerous. One of them, *Kupfernickel*, *Arseniate of Nickel*, but properly an arsenide of the metal, is one of its chief ores. It is stated that, whilst this ore means "false copper," none of the latter metal is contained in it. In opposition to this statement, we may observe that, on frequent occasions, we have detected *much* copper in nickel obtained from this ore, and familiarly known as German nickel in the trade ; and, on one occasion, returned a considerable quantity of the ore as being largely mixed with copper, although sold, by one of the most respectable operative chemists, as free from copper. Kupfernickel occurs in veins of granite, clay-slate, and transition rocks, in various parts of Austria, Saxony, Spain, the Hartz, in the United States, and in our islands in Cornwall, and some parts of Scotland. Two other arsenides of the metal may be named — *Rammelsbergite*, or white arsenical nickel, and *Cloanthite*—in both of which nickel and arsenic are contained in the proportion of single equivalents; whilst kupfernickel contains two of nickel to one of arsenic. A sulphide of nickel is found in *Millerite*, or nickel pyrites. In *Briethauptite* nickel is associated with antimony, in the proportion of two equivalents of the former to one of the latter. This ore is found, with ores of cobalt, at Andreasberg, in the Hartz.

The reduction of nickel from the arsenides previously mentioned, but especially kupfernickel, may be effected in the following manner : —"The ore is first dissolved in a mixture of dilute nitric and sulphuric acids. The nitric acid converts the arsenic into arsenious acid ; and nickel, being changed into oxide of nickel, unites with sulphuric acid to form the sulphate of nickel. The liquor is evaporated, when most of the arsenious acid crystallises, and is deposited. Carbonate of potass is next added ; and the solution being crystallised, yields a double sulphate of nickel and potass. This salt may be slightly contaminated with arsenic, iron, and copper ; but by solution and crystallisation, twice or thrice, it may be completely freed from arsenic. Copper may be separated by precipitation with hydrosulphuric acid (which neither throws down iron nor nickel) ; and, finally, the oxide of nickel may be obtained free from the oxides of iron by the action of liquid ammonia, which dissolves the former, but leaves that of iron untouched. Oxalic acid will precipitate the oxide of nickel from its solution in ammonia, as an oxalate of nickel ; and this, on being ignited, affords metallic nickel. A degree short of redness suffices to effect this decomposition ; but the resulting nickel only aggregates into a button when the heat applied is intense. If the metal be required in this condition, portions of the dried oxalate are to be rammed into a charcoal-lined earthen crucible, and exposed for not less than two hours to the strongest blast of a smith's forge, or a wind-furnace in excellent working order. Metallic nickel may also be obtained, in a spongy state, by transmitting a current of hydrogen over oxides of nickel, heated to redness in a porcelain tube; or, in the condition of a metallic button, by exposing the oxide, mixed with sugar, starch, charcoal powder, or other carbonaceous substance, to the highest heat of a smith's forge, in a charcoal-lined crucible." By this operation the metal absorbs a portion of carbon, and passes into a state analogous to steel, being a carbide of nickel, as steel is a carbide of iron. The mutual relations of those two metals are thus still further established by this fact.

The alloy of nickel, in various proportions, with zinc and copper (called German silver), and with antimony, &c., to form nickel silver, have been already named as the chief uses of the metal. We have also stated that it can be deposited, by electro-chemical decomposition, A company was formed in 1880, in the north of England, to carry out extensively the art of nickel-plating. In experiments that we tried the cyanide, made by dissolving the oxide in excess of cyanide, of potassium, has given the best results. The difficulty of depositing a good coat is considerable; but that of removing it

without injuring the subjacent metal on which it is plated is far greater; and, perhaps, for this reason the deposition of the metal by electro-chemical agency prevented it being commercially adopted. As far as our experiments tend, we consider that nickel is as white as silver when so thrown down; and, in respect to wear, it far exceeds any other metal, but more especially as an electro-deposit, which is always of less hardness than the solid metal goods, for reasons already mentioned when we described the alloys of gold and silver, at p. 186, *ante*, effected by the addition of copper, to give resisting power to ordinary friction or attrition.

The chemical relations of nickel much resemble those of iron. With nitric acid it affords a nitrate, that gives beautiful but highly deliquescent apple-green crystals. The sulphate of nickel much resembles the protosulphate of iron in all its relations. Anhydrous—that is, free from water—all the combinations of the oxide of nickel have a yellowish colour; but, with water, a beautiful green.

In acid and neutral solutions nickel affords no precipitate with hydrosulphuric acid (sulphuretted hydrogen); but a black sulphide, insoluble in hydrochloric acid, with hydrosulphate of ammonia. A green hydrate is thrown down from its salts in solution by caustic potass, insoluble in excess; but, by ammonia, a similar precipitate is soluble in excess: cyanide of potassium gives a green cyanide; but, in excess, forms a double cyanide of the two metals, of a brown colour.

Cobalt.—This is one of the metals that have not been employed in the metallic condition for any useful purpose, although very recently it has been discovered, that its presence in small proportions in iron, tends greatly to harden the latter metal. In many respects it resembles that metal. Indeed, nickel, iron, and cobalt are almost invariably associated together in meteoric iron. The specific of cobalt is about 8·5, and in this respect again it resembles the other two. It is highly infusible and magnetic; but less so than iron or nickel. The preparation or reduction from its ores, generally containing nickel, is similar to the methods adopted with the last-named metal, the oxalate being formed and decomposed like that of nickel; and a metallic button may be produced by the action of intense heat. *Smaltine*, an arsenide, one of its ores roasted, mixed with fine silicious matter and potass, and powdered, affords the smalts used for colouring purposes. Its oxide tinges glass of a beautiful blue colour, and it is also employed in colouring porcelain. These are the chief commercial or manufacturing uses to which cobalt is applied.

Manganese.—This metal, like cobalt, is valueless in its free metallic form, being so readily oxidisable as quickly to crumble into powder by the action of the atmosphere. On reference, however, to p. 61, *ante*, it will be seen that, united with iron in the form commercially known as "spiegeleisen," it is of great importance and value, especially in connection with the Bessemer process in the manufacture of steel. It is largely distributed in nature, and is met with in *Manganite*, its sesquioxide; *Pyrolusite*, the prismatic oxide, and one of the chief ores; *Varvicite*, *Pollianite*, *Braunite*, &c. Two native sulphides are *Alabandine* and *Hauerite*; those previously named being chiefly oxides of the metal.

The reduction of manganese, like that of iron, is only effected with great difficulty, by heating the carbonate, first to convert it into protoxide, and then exposing this, with powdered charcoal and a flux, to a most intense heat, when a button of the metal may be obtained, which, however, in this condition is not pure, but a carbide analogous to cast-iron. Manganese, in its metallic form, has a specific gravity of about 8·0; is brittle, and, to be preserved, must be kept under the surface of mineral naphtha, to prevent access of air, and consequent oxidation.

As previously intimated, its combinations alone make it of any value. Its binoxide, or black oxide, is largely employed to afford oxygen gas, by heating it to a dull red heat; and, mixed with common salt and sulphuric acid, or with hydrochloric acid, it is the commercial source of chlorine, for bleaching powder, in the manufacture of chloride of lime. For such purposes, its native oxide, *Pyrolusite*, in a powdered state, is used, being, however, frequently adulterated to such an extent as to make it all but valueless for the applications thus proposed. We have attempted to use "oxygen," prepared by heating the commercial black oxide, so impure as to produce a gas, in which a common candle would *not* burn, far less exhibit the usual phenomena of light and heat expected from oxygen in a purer state than as found in the atmosphere. This is due chiefly to the presence of carbonates and organic matter, which, when heated, cast off so much carbonic acid as to rather distinguish the gas so produced by the qualities of the latter, than those of oxygen which it should afford.

In the manufacture of glass this oxide is also of much importance, as it serves for an oxidating agent, if, in the presence of organic matter, iron or lead become deoxidised in the melting-pot. Manganese also communicates a beautiful amethyst colour, which is frequently adopted for ornamental purposes. As an acid, the manganic, or permanganate of potash, Condy's and other similar disinfecting fluids, are dependent on it.

Chromium.—This metal, like the two preceding, although of no present use in its metallic form, is of value, to a great extent, under certain combined forms. Its chief ore is a chromate of iron, known as *Chromite*; but it also occurs, united with lead and copper, in *Vauquelinite*, and as a chromate of lead in *Lehmannite* and *Phœnicite*.

In nearly all respects—reduction, &c., except specific gravity, which is about 6·0—it resembles iron in its metal relation. It is reduced from its oxide by making that into a paste with oil and charcoal powder, and exposing it to the highest possible heat of a furnace, when it may be obtained as a carbide, analogous to, and remarkably like cast-iron. It is brittle, exceedingly hard, oxidisable at a red heat, and all but infusible.

Its oxides, as already named, are used in glass-staining; the metal, indeed, derives its name from the variety of colours it is capable of producing by combining with various other substances. If the ore (chromate of iron) be fused with nitre, chromate of potass is formed; and on the addition of sulphuric or acetic acid to this, a portion of the base is removed, and the bichromate of potass afforded. This salt produces beautiful crystals of a rich orange colour. A solution of this salt, added to one of a salt of lead, the acetate or nitrate, affords yellow chrome: and, by boiling with lime, this gives orange chrome—both pigments of considerable use for house-painting, paper-staining, &c.

If cotton and other goods be first immersed in a solution of acetate or nitrate of lead (and occasionally, for certain reasons not necessary here to detail, the two are combinedly used), and the goods be subsequently immersed in a solution of bichromate of potash, beautiful and permanent yellows may be produced, modifiable to an orange by boiling with lime. Hence, although of little use as a metal, its compounds are of economic value.

The four metals which we have thus described —nickel, cobalt, manganese, and chromium— are obviously of much interest for the applications in which they are of value; but, philosophically, they are as much so in the intimate relations that they stand in to each other, and especially in being isomorphous. Thus, physically and chemically, they are united, not only among themselves, but also to iron by many ties, that have, in succession, been pointed out.

Cadmium may be dismissed very briefly. It is chiefly of interest as being a metal associated with zinc, from which it is separated during the process of distillation of the latter metal, described at p. 119, *ante*. It generally occurs in the calamine from which zinc is extracted; and is first recovered, or reduced, through being more volatile than zinc, its presence in the vapour being recognised by a brown blaze. It is soft, malleable, and ductile; has a specific gravity of 8·7; is but slightly acted on in the air; and, although at present of no particular commercial application, possesses such properties as may, eventually, render it of some service in the arts.

Bismuth is a metal of considerable use as an alloy, and is found native in many parts of Europe. Its colour is of a reddish-white; and it is much used with various metals, as in pewter, solder, and imitations of silver; some of which have been mentioned at p. 135, *ante*. It is generally obtained, by fusion, from the matter with which it is found native; and freed from sulphur, arsenic, &c., by fusion with nitre, which oxidises these substances, and so separates them from the metal. It may be obtained in beautiful crystals by melting a few pounds in a ladle, and, when the metal has solidified externally, breaking the crust, and allowing the melted portion inside to run out. The crystals are fine specimens of a rhombohedral form. Its fusing-point is about 590°; but if alloyed in the proportion of eight parts of bismuth, five of lead, and three of tin, it affords a mixture that will melt at 210° Fah.; and an alloy of two of bismuth, and one each of lead and tin, fuses at about 200°. Such an alloy may be used to take copies of coins, and for moulding generally; indeed, in the earlier days of electrotyping, such was the usual plan of procuring fusible moulds for that purpose. Its chemical combinations have no use in the arts, except so far as they are employed, to a limited extent, in medicine, and most perniciously as pearl powder for cosmetic purposes, in which condition they are about as sure a device for injuring the skin and the health of the user, as any possibly can be made.

Antimony.—This is another of the metals that is of great value in an alloy, several of which have been described at p. 135, *ante*. Its chief ore is a sulphide, which is found in veins of granite and slate, in Cornwall, Saxony, the Hartz Mountains, &c. We have seen some very rich specimens of this ore sent from Borneo, where it is exceedingly abundant. Antimony occurs native in veins of some crystalline rocks in Bohemia, the Hartz, at Andreasberg, in Sweden, and other places. Allied with silver, as *Antimonsilber*, it occurs also in the Hartz, in Spain, France, and Mexico. *Briethauptite*, already mentioned in connection with the ores of nickel, occurs with the ores of cobalt, also, at Andreasberg. The metal, however, is almost entirely obtained from the sulphide, which, after being fused, is heated with iron or carbonate of potass. The sulphide is technically known in commerce as antimony, the metal itself being called regulus, or regulus of antimony, a remanet of alchemical nomenclature.

Antimony, in the metallic form, presents a beautiful plate-crystal-like appearance. It is very brittle, and has, therefore, neither ductility nor malleability; indeed, it may easily be reduced to powder. It has a bluish-white colour, and fuses at a temperature somewhat below redness. Its specific gravity is about 6·8. Exposed to air and moisture, it barely loses polish for a long time; but is rapidly oxidised by nitric acid, aided by heat.

As a rule, antimony enters into alloys for the purpose of hardening them; and, consequently, with tin it is a chief constituent of pewter. But one of its most important uses is that of forming type-metal and stereo-casts, from type set up in formes. Its value for this purpose arises from the fact, that, like water, it forms an exception to the general, and all but universal, rule, that bodies contract by cooling. Antimony, on the contrary, as it cools, expands; and hence, united with lead, and cast in type-moulds, it affords an excellent and exact copy, expanding into every orifice of the mould in a manner that no other metal would do. Again, for stereotyping, it is valuable for another reason—for forming an alloy with lead, which keeps fluid at a temperature below what is required to char paper. The latter material can be employed, in place of plaster of Paris, to take a copy of the type in formes; and it gives a much better mould than the plaster, formerly used, can do; besides which, there is no danger of

pieces of paper breaking away, or of the mass cracking—both of which constantly happened when plaster of Paris alone was employed.

Its combinations are also important. The tartar emetic of medicine, as also antimonial wine, &c., are of great value in several complaints. The sulphide, already described as its ore, is largely employed in pyrotechny for the purpose of affording a blue light when mixed with nitre and sulphur. With hydrogen, antimony unites to form an inflammable gas, known as antimonietted hydrogen—a combination remarkably similar to that of arsenic under identical circumstances.

Arsenic.—In a work professedly on metallurgy, little can be said of this metal; in fact, it has no uses whatever in a metallic state, its properties of that kind being brought into use, not by mixing metallic arsenic with other metals, but by the use of arsenious acid. United with other bodies, it is one of the most universally diffused substances in nature; for there is, with scarcely an exception, no metal that we have previously described at any length the ores of which are not connected with, or formed by some combination of arsenic, either as an arsenide or arseniate. Its only use, nominally as a metal, is to harden lead for shot; but in other forms its employment is somewhat extensive.

The metal is readily reduced from its white oxide (white arsenic of commerce, or arsenious acid) by heating this substance in a close vessel with charcoal powder. It has a steel-gray colour; is very brittle; has a specific gravity of from 5·7 to 5·9; and, by heat, is readily converted into arsenious acid, the well-known deadly poison. United with copper, it affords the beautiful but dangerous pigment called "Scheele's green," employed in dyeing, paper-staining, and colouring the leaves of artificial flowers; for all of which uses it is exceedingly improper, and, in fact, very dangerous, as already pointed out at p. 142, *ante.* Realgar and orpiment are both sulphides of arsenic; and they are used as pigments, and also in pyrotechny. A very recent and additional employment of arsenic is in acting upon aniline, &c., in producing some of the most beautiful of the coal-tar colours. It has also been used as a cosmetic, to wash sheep, and steep wheat; mixed with the food of horses, to give the sleekness of coat; and last, and perhaps more singular of all, there are districts, chiefly mountainous, in Europe, where arsenic-eating is just as prevalent as opium-eating is in other countries. The effect on the system is that of giving a roundness or plump appearance to the skin; but, more especially, it is said to prevent exhaustion and loss of wind in climbing steeps, for which purpose it is thus mostly partaken of.

Aluminium and *Magnesium.*—These two metals form the latest addition to our stock of metallic bodies producible on the large scale, and resulting from processes of a much more refined character than any, with the exception of platina, amongst metals in ordinary use; and as the process of reducing them is all but identical in principle, they may be conveniently considered together, more especially as they both form earths by oxidation.

Alumina is a white earth, abundantly obtained, by precipitation, from a solution of alum by an alkali; ordinary alum being a double sulphate of potass and alumina. It largely enters into the composition of clay of all kinds, which, in fact, is a silicate of alumina; that is, a union of silex, or pure flint, and alumina. It is a component of many substances, as pure clay—used for porcelain-ware—brick clay, rubies, and many other precious stones. Indeed, as we have already shown at p. 164, *ante*, when dealing with gems, they, with but few exceptions, are chiefly constituted of either or both of these earths.

Alumina is a sesquioxide of the metal aluminium, analogous to the red or sesquioxide of iron. Indeed, we regard the constitution of alumina more from analogy than real analysis, considering it to consist of two equivalents of the metal united with three of oxygen.

In dealing with all the ores of metals (previously described as oxides), it will be found that the usual method of reducing or obtaining the metal is that of presenting some other substance capable of uniting with the oxygen of the oxide—generally carbon, in the form of coke or charcoal, aided by a more or less intense heat; and thus the oxygen uniting with the carbon, to form carbonic acid, sets the metal free. Such is the entire philosophy of the smelting of iron, copper, lead, tin, zinc, and, indeed, most metallic ores that are oxides.

But aluminium has far too great an attraction, both for oxygen and a portion of combined water, to permit of thus reducing it by heating it with charcoal. In vain, when Deville first intimated his success, did we try, with the most intense heat of the blast or wind-furnace, to obtain that result. The alumina showed no sign of reduction whatever.

Yet there are other combinations of aluminium that are more tractable, and other materials also for its reduction: the chloride and fluoride are both of this class; but as the method for reducing both—the latter being found abundantly as *cryolite* in Greenland, and now largely imported, for making aluminium, by ship-loads—is almost identical, we shall prefer to indicate that pursued with the chloride, as illustrating the general principle of all the methods; but especially that of Deville, to whom we are indebted for its production in quantity in the year 1855, although an exactly similar process was pursued by Wöhler, who discovered the metal in 1827.

But the first point to be noticed is the reducing agent employed. This is not charcoal, but the metal sodium, to which we have already alluded as discovered by Davy in the beginning of this century, and which laid the foundation of his world-wide fame as a chemist. The method which he adopted was that of placing a piece of moistened soda between the poles of a powerful voltaic battery, the electro-chemical decomposing action of which separated the oxygen from the metal, setting the sodium free; this he collected as an amalgam by means of mercury.

By distillation of this amalgam he thus got the sodium in small quantities. Subsequently, by incomplete processes, the metal was produced in large quantities; but till about twelve years ago, its price was generally from 10*s.* to 12*s.* per ounce, whilst now it is less than that per pound; and it is this decrease of price that has chiefly led to the production in quantities of aluminium from any source, rather than the invention of new processes.

The present method of producing sodium is to make a mixture of acetate of soda and charcoal, and ignite it to produce a carbonate; or to melt ordinary carbonate of soda in its own water of crystallisation, and, while fused, to mix it intimately with finely-powdered charcoal, and drying. The mass is then introduced into a wrought-iron or fire-clay retort, from which passes a tube, the outer end of it dipping into some mineral naphtha, which, being free from oxygen, keeps the sodium from danger of oxidation. The retort is exposed to intense white heat, and thus the soda is decomposed, the oxygen of it uniting with the charcoal to form carbonic acid; whilst the sodium, being volatile, distils over, and is condensed into drops in the mineral naphtha. It is, however, in this condition in a very impure state; and it is, consequently, melted (its fusing-point being less than that of boiling water) under the naphtha in a cylinder, in which fits a piston, pierced with minute holes. When the sodium is completely fused, the piston is forced down, and the sodium rises through it just as if it were a sponge; and thus it is freed from most impurities.

Sodium so prepared has an astonishing affinity for oxygen, chlorine, &c. If a small piece be thrown on a little warm water, or placed on a little damp bibulous or blotting-paper, it instantly decomposes the water, and, setting the hydrogen free, combines with it, evincing so much heat that the metal and gas unitedly burn with a brilliant yellow flame. We may state, parenthetically, that the preparation of potassium from potass, and the properties of the metal so produced, are all but identical with those just described in respect to sodium.

In the latter metal we have, therefore, a powerful agent for effecting decomposition; and, accordingly, it is employed in reducing aluminium from its chloride, or fluoride, previously named.

Deville's process, which has, since its first introduction, received certain modifications in detail, is as follows:—Alumina, produced in the manner already explained, is made into a paste with charcoal finely powdered; oil or syrup being used to make the mixture as intimate as possible. The mixture is then ignited in a close crucible, by which the carbon of the sugar or oil is set free in minute particles, that favour the chemical action of subsequent processes. The mass, on cooling, is removed from the crucible, broken into small pieces, and introduced into a tube, originally made of platinum; but a porcelain or fire-clay one answers. The tube is placed in a furnace, so that it can be heated red-hot. At one end of the tube is fitted an apparatus, by which chlorine can be produced gaseously; and, at the other end, a smaller tube leads from the one containing the alumina, into a close vessel intended to receive the chloride that will be formed. All being prepared, the fire of the furnace is kindled; and on the large tube becoming red-hot, chlorine is passed into it; the heat surrounding the large tube, together with the action of the chlorine, decomposes the alumina, and produces the chloride of aluminium, a yellow volatile powder that collects in the receiver above mentioned. Being highly deliquescent, it is carefully excluded from the air.

When sufficient of the chloride is produced, it is removed and placed in a crucible, in which is some of the metal sodium already described: the top of the mixture is covered with common salt and a crucible cover, and the whole is exposed to heat in a furnace. Gradually the chloride of aluminium is decomposed, its chlorine uniting with the sodium to form common salt; whilst the aluminium is set free, and recovered as a metallic body.

The first bar of the metal that reached this country, was sent over to the Royal Polytechnic Institution, London, by the Emperor of the French; and on this we tried several experiments at the time (1855-'56), the interest of which has entirely passed away, owing to the present abundance of the metal. Its colour is something like a combination of those of silver, tin, and zinc; but much depends on its purity. The specific gravity of aluminium is about 2·6. It is malleable, ductile, a good conductor of heat and electricity; unaffected, to any appreciable extent, by air and moisture, or even sulphur; and, in the latter particular, is therefore superior to silver. It is highly sonorous, and, consequently, elastic. It is capable of forming several alloys; and those with copper have already found great favour for manufacturing pencil-cases, watch-cases, &c., &c., because they so greatly resemble gold as to be barely distinguished from that metal. "Aluminium, alloyed with 2 per cent. of nickel, becomes less blue in colour, is harder, and rather more difficult to forge than pure aluminium. For this purpose it must be heated to a dull red; while pure aluminium can be worked at a much lower temperature. The compounds which aluminium forms with copper are especially worthy of notice. When these metals are alloyed in the proportions of one of aluminium to nine of copper, the bronze so obtained possesses great malleability and strength. Professor Gordon ascertained that, with wires of the same diameter, the strength of aluminium bronze, iron, and copper, stood in the following relation to each other:—

" Aluminium Bronze	155
Iron	100
Copper	68

"Three compounds can be formed with copper, distinct in their colours and properties. One, containing 5 per cent. of aluminium, is of a beautiful gold colour, and takes a splendid polish. It is of great malleability; and, by

being hammered when cold, acquires great hardness, and a grain similar to that of copper. Another contains $7\frac{1}{2}$ per cent. of aluminium, and is of that greenish gold colour which is known to be the result of an alloy of gold with silver; it is very fibrous and malleable when cold, acquiring, like the bronze of 5 per cent., when hammered cold, great hardness. It is capable of a very beautiful polish. A third compound of copper and aluminium contains 10 per cent. of the latter. It possesses great malleability and strength. These are much increased by a moderate amount of hammering when cold; after which, owing to the greatly augmented hardness of the alloy, further action of the hammer becomes useless. At a red heat it very readily admits of being forged and rolled; and if, when well heated to redness, it be left to cool down in the air to a dull red, and be then plunged into water, it becomes sufficiently malleable, when cold, to bear, without fracture, every kind of manipulation practised in the industrial arts. We have already noticed some of the alloys of this metal with copper in a chapter describing the latter.

Gradually, there is no doubt that aluminium will, from its peculiarly valuable properties, obtain a position that will rank it, not only amongst the most useful, but also amongst the most common of metals. We have already seen that, about a century ago, zinc fetched ten times its present price; whilst, in respect to aluminium, its price has been reduced to the twentieth part of what it was ten years ago. We fully echo the following opinions of one quite capable of forming an accurate judgment on the question, when he states—"From the facts related, I conclude that aluminium is a metal destined to become one of the useful class, from its curious properties; by its power of undergoing no change in colour or lustre by the action of air, or of air charged with sulphuretted hydrogen; by its resistance to the action of acids; by its fusibility; by its beautiful colour, and its physical properties generally. Its density, so low as to be scarcely equal to that of glass, will ensure for this metal special applications. Intermediate between the common and precious metals, from certain properties it possesses, aluminium is superior to the first group for domestic purposes, by the absolute inocuousness of its compounds with the feebler acids. When it is further remembered that aluminium exists in considerable proportions in all clays, amounting, in some cases, to one-fourth of the weight of a very widely diffused substance [common clay], we cannot do otherwise than hope that, sooner or later, this metal may find a place in the industrial arts."

To a considerable extent this has been already accomplished; but there is no doubt that, as fresh discoveries arise, the price of aluminium will be greatly reduced; and that, eventually, it may become, from its abundance, a "common" metal.

In respect to *magnesium* little need be said. It is, like aluminium and calcium, abundantly diffused in combination over the whole surface of the globe; but especially, in our country, is present in magnesian limestone, the source of that well-known substance—at least commercially—Epsom salts. As a metal, it has yet had no applications except such as arise from its great inflammability, and the consequent production of a most brilliant light, only second to that produced by the disruptive discharge of the voltaic battery. It has been partially adapted as a general illuminating agent, most successfully by Mr. Larkin in a lamp, wherein the metal is burnt as a fine powder. For photographic purposes, precisely the same objection must be urged against the light it produces as holds good in respect to the lime and electric lights; that is, an almost complete absence of diffusive power, and, consequently, a want of tone or gradual melting of light and shade of photograph produced by its action. For this there seems to be no remedy, unless some new discovery be made, whereby we shall obtain an at present unknown power over some of the properties of light, which, from the present condition of physical and chemical science, we have no reason to expect.

We need not here much further allude to some of the uses to which magnesia (the oxide of magnesium), together with several of its combinations, are applied. Medicinally, calcined magnesia, its carbonate, and the sulphate, or Epsom salts, are all well known as of extensive employment. In the form of magnesian limestone—that is, the carbonates of magnesia and lime united together—we have one of the most valuable building-stones of Europe. Respecting this, Professor Ansted remarks—"Those magnesian limestones which are valuable for building purposes, consist of nearly equal parts of carbonate of lime and carbonate of magnesia, in a state of perfect combination, and of crystalline texture. The colour is peculiar and agreeable, being accompanied by a singular pearly lustre. The specific gravity is high, the best stones weighing 150 pounds to the cubic foot. The cohesive power is very great; specimens of the stone cracking at 5,000, and crushing at 8,000, pounds to the square inch of surface." But the value of this class of stone must be considered *cum grano salis.* It was employed for constructing the Houses of Parliament at Westminster; and not long after their erection, it was discovered that this kind of limestone (species of *Dolomite*) is by no means so well adapted, under all circumstances, as was at first supposed. In large towns, acid and alkaline vapours or gases are constantly being given off; and hence, what might answer extremely well as a building-stone in clear fresh air, such as that enjoyed in ancient cities whose remains are still with us, is extremely unfitted for similar modern purposes where other conditions prevail.

We have thus endeavoured to give as ample an account as our space will permit, of all those particulars that are of interest in connection with coal and metal-mining; the reduction or smelting of ores; the preparation of the metals for useful purposes in the arts, manufactures, and social

life; their alloys, and the chemical combinations that are, in some cases, as valuable as the metals themselves in an economical point of view.

Taking the raw material that nature presents us with, in the mineral, vegetable, and animal kingdom, it will be seen that the metals take the highest rank. Although mostly the dust of the earth in respect to their ores, by the application of the intelligence and industry of man, they become one of the chief elements of his existence, comfort, and luxury. They rank amongst the earliest objects of his attention, study, or useful application; and although their general adaptation has been a work of ages, still, in some form or other, they have always been identified with that which concerns his existence, for necessary or ornamental purposes.

Although it has been impossible for us to have traced satisfactorily the gradual development of the uses of each as it has been discovered, sufficient has been adduced to show that such a development is of the most interesting character, simply because, as just stated, it is more or less identified with the history of mankind. In sacred or profane writings, metals are always an element of much detail. The gorgeous description of the Temple of Solomon, or those of Persia and India; the domestic and warlike implements of ancient civilisation and barbarism, equally with those of modern days; the shield of Achilles; the household utensils of Pompeii; or the machinery of modern Europe—all are identified with metallurgy, and, as such, form an important element in all that appertains to our existence.

It was reserved, however, for almost our own day to discover not only new metals, but also the uses of those long before known. In olden times, the only guide of workers in metals was, first imitation, and subsequent sparse and laborious improvement, unaided by any rule, law, or induction. Each worker did that which was right in his own eyes; or, in other words, there was no rule of working artistically or chemically.

In our own opinion, there are few matters of more special interest in the preceding pages than the account of the present mode of iron-smelting, and general preparation of the metal, in Persia and India, given at p. 69, *et seq.* It brings us back at least 3,000 years in the world's history, although of present adoption; and, by comparison, it shows what modern science has done for man. In former days, Persia and India (as at present) were amongst the most populous nations of the world; both were, and are, favoured with natural advantages rarely possessed by any other country; and yet, despite them all, the iron manufacture has not made the least advance, certainly through a period of one hundred generations, so far as unaided by European science and enterprise.

Turning to our own country, one-thirtieth part of that period, or a little over a century, has rendered our manufactures of iron a necessity to, at least, seven hundred millions of the human race; indeed, practically, half a century has done more for us, by advances in applied science, than had previously half the established chronology of the world's history. A moment's reflection will convince the most desultory reader that such a circumstance is not an accident, and cannot be without the greatest significance. Whence has arisen that wonderful stimulus to the mental and physical power of man, that, in fifty years, should cause a generation to outstrip, so far as history teaches us, all the numerous generations, individually or collectively, that have preceded it? Can it be supposed that, at this period of the world's history, man is culminating as man in intelligence, in the power of mind over matter? Or are we rather (and which is more reasonable to suppose) entering on a new page of the history of mankind, in which brute force is at last submissive to mind-force, and a partial omnipotence and omniscience becoming the prerogative or quality of our race?

To answer such questions, or even to enter on such speculations, although properly suggested by the facts that have been adduced, is not within our province. On the contrary, considering the question in its purely philosophical and practical aspects, our views, opinions, and speculations become rapidly sobered down. After all that has been done, but little real progress has been made in research into the riches of a mineral character that exist. Taking our own country alone, the total amount of coal and mineral matter that has been extracted from the bowels of the earth, is a mere speck compared to what may be derived. And leaving Europe (in every country of which the same remark equally applies), we may properly denominate America—North and South—as a *terra incognita*, a new world yet, so far as its mineral treasures are concerned.

Geology, as we have frequently shown in the preceding pages, constantly is found at fault as new facts arise. Not only each year, but each week, brings forth some new fact, that partially invalidates previously-formed conclusions. And geology is not alone in such constant corrections, if not falsifications, of its "facts" and theories. In the previous pages, many statements have been advanced in relation to the mineralogical and crystallographic character of substances that, whilst now received as true, are, to use a geological phrase, in a transition state—a condition which, whilst probably lasting as long as man exists, must, nevertheless, get gradually nearer, although little by little, to the truth.

But if we turn to chemical science in its relation to our subject, and to nature generally, we find still further hope and necessity for advance, however much we may congratulate ourselves on what has been done. Let us take a hasty glance at its relations to the subject of mining and metallurgy, to which our attention must here be most confined.

In reference to the preceding portion of this work, we may first notice the points involved in coal and coal-mining, imperfectly pointing out a few matters in which, at present, chemical science is at fault, and is required to investigate.

With regard to the cause of explosions in coal mines, and their prevention, much as the investigations of Davy, Faraday, and others have done, we are yet without any certain preventive means of the effects, and still more so in respect to the cause, of the explosions.

That Sir Humphry Davy's invention of the safety-lamp was a great boon to the coal miner, cannot be doubted. It has been the means of saving thousands of lives, and generally may be trusted under all ordinary circumstances. But it doubtless fails frequently at the very moment when it is required to be most effective; that is, at the instant when a sudden outburst of inflammable gas takes place, that, without the least warning, not only places the men working at that particular part of the pit in danger, but jeopardises all who may be engaged in it. Such has occurred in the fearful accidents in most of our collieries during recent years.

It is by no means certain whether or no the peculiar gauze-like form of the safety-lamp, as now constructed, may not facilitate explosions on a principle analogous to that under which dialysis is effected; that is, the influence of extremely minute orifices in facilitating, rather than preventing, the production of flame under certain circumstances. The principle of the Davy lamp rests on the fact, that masses of metal prevent the passage of flame through such apertures by the cooling power that the metal possesses. On the other hand, the effects of platina in foil, sponge, wire, and powder, have exactly opposite results; and we are not yet quite sure whether such results are due simply to the catalytic effect of the platina, to its absorption of hydrogen and oxygen, &c., or to the effect of a perfectly clean metallic surface, which may afford an opportunity for nascent union in the absence of the action of the oxygen on the metal. At the moment of explosion, it is perfectly possible that either a copper or iron wire gauze may, by the reducing effect of the hydrogen present in the fire-damp, become so completely clean as to thus act as an igniting agent between the gas external, and the flame internal, to the lamp.

Again, the nature of the gas given off from coals in the mine, has been, up to the present time, by no means satisfactorily investigated. Our space would be far too much occupied were we to attempt to adduce here all the varied opinions, likely and unlikely, that have been offered to explain its nature. Indeed, many of them are not founded on fact, but on certain theoretical views that their propounders entertain. Therefore such opinions are only worthy of notice in proportion either as they are founded on fact, or, at all events, if theoretical, explain a series of dependent and connected facts satisfactorily.

But to all these opinions one objection arises; which is, that they do not explain how it is that explosions of "coal" gas take place on board ship—a matter of constant occurrence, and frequently of serious consequences. We can well imagine, that if a ship were loaded with one large, solid mass of coal, its accidental fracture on board the vessel might, by the sudden issue of pent-up gas, cause an evolution of the latter, which, on approaching flame, would become ignited. But when, as we all know, coal is shipped on board in pieces no larger than those in domestic use, and, except in the fact of its being enclosed in a ship's hold, it is placed in no essentially different circumstances than that of an ordinary coal-cellar, saving that the ventilation is not so perfect, still the inquiry is to be satisfied—How, and by what chemical agency, can a mass of coal produce gas from its body or surface at ordinary temperatures, and in such quantities as produce the explosive effects to which we have directed attention? The result is against all our ordinary experience of chemical action; for it has never been proved that coal can heat unless it is largely charged with iron pyrites; but still this, whilst it might cause an explosion by ignition, would certainly not produce, in the first instance, the evolution of the gas, which is the ultimate cause of such explosions. The only conclusion at which we can arrive is, therefore, despite all our chemical knowledge, that of the laws of the constitution of even the best known hydro-carbon is, at present, on a very limited scale.

Turning to the next subject—that of iron ores and iron-smelting in relation to chemistry—we see, however great our advances (even including in our consideration that splendid triumph of science applied to manufactures—we mean the Bessemer process), chemistry has yet much to do for this branch of metallurgy. With the exception chiefly of Durham coke of a peculiar kind, most of the fuel of the iron-smelter, at least, communicates sulphur, arsenic, silicon, &c., to the metal which it is intended to smelt. Hence, to some extent, the great variety of "irons" produced. Again, the presence of phosphorus, so exceedingly injurious to iron in any form, as injuring its tenacity, was a blot on our chemical knowledge that has but just been removed. In our previous pages, when speaking of the ores of the Cleveland district, it has been pointed out, that the presence of phosphorus entirely unfits Cleveland iron for the Bessemer process; and, indeed, that the great want of our country is ore free from that unfortunate element to the iron-master; hence, in part, the large importation of spiegeleisen from Germany, and of pure iron from Sweden, to be here converted into steel. In our remarks on this subject, we have given the latest experiments that have been tried to obviate the evil, previously unprovided for; and which promised, under the present method of the iron and steel manufacture, seriously to affect our smelters. It is to be hoped, however, that the Thomas-Gilchrist process, fully described in this work, has met the difficulty successfully.

Another point in relation to chemistry and iron manufacture, where we are still at fault, is in regard to the constitution of steel. Within the last thirty years, we have come across numerous theories in books, and propounded verbally by practical men, to account for that constitution. At p. 101, *ante*, we recounted experiments of Faraday and Stodhart, intended to give purity and other qualities to steel,

by the introduction, in minute quantities, of metals other than iron. Since the date of these experiments, carbon, nitrogen, manganese, and other substances, individually or collectively, have been assigned as essential to the constitution of steel; and among other theories that have been promulgated, almost without number, one has been advanced, by a foreign chemist, that nickel and cobalt are *always traceable in iron;* and are also in part, essential to the proper constitution of steel. There is one thing quite certain—*i.e.*, that chemical analysis has hitherto all but failed to account for the varied character and quality of steel, although it has been invaluable, in a measure, guiding us to the best methods of production. Hence the Bessemer-steel invention, and its valuable results: but these, attained by aid of chemistry, *à priori*, have been rather proved of value in their application, than by a scientific *à posteriori* investigation of the consequences of the processes adopted.

But physical and chemical science are, at present, both unable to explain why it is that a graduated temperature, as adopted in the art of tempering steel, should have the singular result of affecting its elasticity, hardness, &c., as effected in that operation. It certainly seems extraordinary, and inexplicable, that so trifling a range of temperature, and such slightly altered circumstances of operation, should change a metal as brittle as glass, and as hard as flint, into one of the most elastic and ductile substances in nature; and equally so, that not alone steel, but copper, zinc, silver, gold, and most other metals, after having been submitted to such operations as hammering, rolling, and the like, should have all their softness, pliability, &c., returned by the simple operation of heating.

Grouping, for the moment, in connection with iron, two other metals—nickel and cobalt—physical science has yet to explain how it is that, so far as our present knowledge is concerned, these three alone are the subjects of magnetic influence, either of attraction or polarity; and, still further, how it is that an increase of temperature may, and does, greatly affect their magnetic character. It is a singular fact, that these three metals are, almost without an exception, simultaneously found in any specimen of meteoric matter cast on to the surface of the earth; whilst nickel is never (with the supposed exception in regard to the experiments of the chemist, just referred to) found in terrestrial iron. Practically, at all events, the latter is, at present, an almost universally established fact.

It is impossible to explain such phenomena on any grounds, so far as this peculiarity depends on chemical or mechanical characters; for the analogies of these, in respect to the metals now in question, extend themselves to others that have not the slightest indication of being magnetically affected. On the broad view, we know that every body can be brought under the general influence of magnetic action; hence that branch of science whose province it is to collect and expound dia-magnetic phenomena: but here we confine our remarks, in respect to magnetism, solely to the evidence of its presence, as shown in the effects of polarity and attraction.

The next subjects in order of metallurgy that were undertaken in the previous pages, were copper, tin, lead, and zinc, and their alloys; and, in connection with these, many matters, in respect to which both physical and chemical science leave us in the dark, may be pointed out.

The formation of metallic veins, at least, of these metals, is a subject that has yet entirely eluded our grasp satisfactorily to dispose of. On this subject we have already given some account in its proper place, together with the result of some experiments made in connection with the supposed electrical influences that have been exerted, in certain cases, in depositing metals in their native condition; which may be discovered by man as at first formed, or which, in the lapse of time, by the agency of air, moisture, heat, sulphur, and arsenic, may have become, in the case of the base metals, the sources and causes of the ores that we now avail ourselves of for the supply of such metals.

As, however, subsequent to the remarks thus made, we have had occasion to explain the circumstances under which the ores, or reguline metals of other kinds, are found, it may not be amiss, at this place, to make a few additional observations on the whole subject; because, having taken a view over the whole of the metal kingdom, our present remarks can be made of a more generalised nature.

Four distinct theories have been, at different periods, offered to account for the production of metal veins. The aqueous theory, or that of Werner, founded on local rather than general observation, accounts for the veins of ore on the idea of rents or crevices, "open at their upper part, being filled up from above; that the matter they contain was precipitated from solution, or suspended in water, just as beds or strata are formed; that they are of different ages, distinguishable by the mode of deposit of the contents; that they are limited in range and position, and grouped into certain districts." All of which is true in localities, but certainly not in all cases.

On the other hand, the igneous theory of Hutton supposes that "the contents of veins were, in all cases, injected from below, in a state of igneous fusion."

Midway between these two theories is that of Necker, who, on various grounds which we need not here enter into or investigate, supposes that metallic veins were caused by sublimation, the cracks, veins, or crevices being thus filled up by the agency of heat, the almost invariable adjacency of igneous rocks to metallic veins, affording, as it were, the basis of this theory.

Lastly, we may notice the electrical theory, which serves to explain the condition of mineral and metal veins by the agency of the force of electric and magnetic currents. This theory was first prominently put forth by Mr. R. W. Fox, and founded on numerous experiments conducted by him, analogous to that already de-

scribed at p. 38, *ante*, where we illustrated the method of producing veins of metallic copper by a single voltaic arrangement. "Assuming the existence of fissures produced in the solid substance of the earth's crust at various times, and taking it for granted, also, that they penetrate to great depths, are exposed to a high temperature, and must have been filled up progressively, Mr. Fox has shown the probability there is of heated water having been circulated in them by ascent and descent; and the certainty that quartz, and earthy substances, might be deposited from water in that state. He then proceeds to explain, that in such fissures, filled with metallic and earthy solutions, the different sorts of matter on the sides must necessarily produce electrical action, which might be rendered more active by the unequal temperature of the water and the walls of the fissure. Currents of electricity, thus generated, would pass more easily in the fissures than through the rock, and they would pass in directions conformable to the general magnetic currents of the district, and therefore east and west, or somewhat to the north and south of these points, according to the position of the magnetic poles of the period when the process was going on.

"Electrical currents thus circumstanced would deposit the basis of the decomposed earths and metallic salts over different parts of the rocky boundary of the vein, according to the momentary electrical state and intensity of the different points; and the nature and position of the rocks would be influential in determining those conditions. When, by such processes, particular arrangements had happened, new actions might arise, and amongst them a series of secondary phenomena, such as the transformation of ores without change of form—a fact otherwise very difficult to comprehend. Lateral rents might also be filled by virtue of these new actions, even though they were not in the most favourable lines of electrical circulation."

Now an impartial and even cursory view of each of these theories, will be sufficient to show that, whilst each is applicable to particular cases, not one of them can be made of universal application.

Confining our attention to the mineral and metal mines, veins, and beds of our island, and having personally visited them all, from Cornwall to Ayrshire, and the black-band district inclusive, we can entertain not the least doubt that Werner, Hutton, Necker, and Fox would each have been ready, under certain circumstances, with that honesty that characterises true philosophy, to have given credit to any other theory than his own for truthfulness. Thus, while Fox's views are extremely well adapted to explain the origin of the metallic viens of Cornwall and Devon, they are utterly valueless for accounting for the Scotch black-band, that might be far more satisfactorily disposed of on the theory of Werner. On the other hand, the igneous theory, which supposes that metals are injected in a melted state, whilst explaining the occurrence of such veins in granite and other igneous rocks, utterly fails, as does that of sublimation of Necker, when we refer to the lead districts, in limestones, of our own country. Hence, without entering into any long disquisition on the special inapplicability of any or all of these theories, our readers will agree with us in concluding that geology, the sciences of heat and electricity, with that of chemistry, have still a wide field for investigation, before any theory of metallic vein-formation can be satisfactorily and generally established to be true.

Reverting now to the metals copper, tin, lead, &c., we must again point out that our knowledge of the formation of alloys is as yet greatly defective, whether as regards the physical or chemical changes that occur when two or more metals are so united together. We have previously seen that the specific gravity does not, in all cases of alloys, follow, as a rule, the arithmetical mean of the two constituents. Other circumstances, previously mentioned, equally point out how much has yet to be done satisfactorily to settle such difficult questions, pertaining to chemical science more especially.

In a similar manner we might trace, in other subjects that have been brought before the notice of our readers, the great difference that subsists between what we actually know, and what we require to know, in respect to the physical and chemical character of the bodies with which we have dealt in the preceding chapters.

Apart from the metals simply in their metallic character, and as alloys, the progress of chemical science has been much more rapid and effective in its results. We have constantly noticed, whilst describing each metal, how much its varied uses have been extended by chemical knowledge. As previously remarked, each metal, as a raw material, has been constantly made to furnish fresh raw materials from itself; and hence new branches of industry have been called into exercise, new wants satisfied, and others created that yet remain to be met. But a few years ago, the metal manganese was certainly amongst the least useful of any of the series; indeed, as we have explained, it is now of no value except as an alloy of iron in its metallic nature. But the discovery of chloride of lime by Tennant, opened out a new method of bleaching cotton fabrics towards the close of the last century, and reduced the time required for bleaching from two months to two days. But to make chloride of lime, oxide of manganese became necessary; hence its mining soon began to be a most important occupation. A gradually increasing demand for chloride of lime, by the extension of the cotton trade, led to a greater demand for soda, previously made by a roundabout process, but subsequently by the action of sulphuric acid on common salt, with various other processes, unnecessary for our purpose here to enter into. The demand for sulphuric acid led to inquiry after sulphur; and, subsequently, an immense quantity of sulphur, previously wasted by roasting sulphide ores in the air, became saved and utilised. But sulphuric acid required distillation; and as platina alone could be used to make stills for that purpose, the production of that metal became

largely increased. Collateral with the extending cotton manufactures, iron was required for machinery; and thus furnace after furnace, in the black-band district of Scotland, the "black country" of Staffordshire, the iron districts of Wales, was called into operation. These failing to meet the demand, together with that of railway iron, led to the opening out of the Cleveland district, where so much iron is now produced; and thus, by the expansion of one branch of manufacture, arising from the application of chemistry, the trade of the country, and its pecuniary prosperity, have been enormously affected.

It is remarkable, in the production of ores from various districts, how much the centre of operations varies in course of time. In respect to iron, for example, in the time of the Romans, the south of England was the chief place where iron ore was found and smelted, wood being used as fuel; whilst, at the present day, our supplies are chiefly drawn from the northern portion of our islands, which is due to the abundance of coal in those districts. This fact shows how much one branch of mineral processes depends on other. The same may be said of our copper districts; for, of late years, the production has greatly decreased in Devonshire and Cornwall, and hundreds of the miners have left localities where the ore was once got in abundance; a large proportion of our copper ores being now got from Australia, and other countries. Next, again, in respect to lead. In the time of the Romans, Derbyshire was the chief locality for lead-mining; whilst, at the present day, the north of Yorkshire, Allenheads and Leadhills—one so much further north, and the latter in Scotland—are the chief sources of that metal. In respect to the precious metals, gold and silver, this transition has been remarkable. At one time, Brazil, Hungary, some parts of Asia, &c., were our sources for obtaining gold; now our supplies are almost entirely drawn from fresh places, as Australia, California, and Columbia. It cannot be supposed that, in all cases, the previous localities, or mines, were exhausted absolutely; but the temptation of an, at first, extraordinarily increased production in a new locality, draws persons engaged at older sources to them. Thus the miners of Cornwall have flocked to Australia and other countries, spreading the benefit of their experience, and using it frequently to the highest advantage to themselves.

On this subject, and others cognate to it, Mr. Babbage has eloquently remarked—"The productions of nature, varied and numerous as they are, may each, in some future day, become the basis of extensive manufactures, and give life-employment and wealth to millions of human beings. But the crude treasures perpetually exposed before our eyes, contain within them other and more valuable principles. All these, in their innumerable combinations, which ages of labour and research can never exhaust, may be destined to furnish, in perpetual succession, the sources of our wealth and happiness. Science and knowledge are subject, in their extension and increase, to laws quite opposite to those which regulate the material world: unlike the laws of molecular attraction, which cease at sensible distances; or that of gravity, which decreases rapidly within the increasing distance from the point of its origin, the further we advance from the origin of our knowledge, the larger it becomes, and the greater power it bestows upon its cultivators to add new fields to its dominions. Yet does this continually and rapidly-increasing power, instead of giving us any reason to anticipate the exhaustion of so fertile a field, place us, at each advance, on some higher eminence, from which the mind contemplates the past, and feels irresistibly convinced that the whole already gained bears a constantly diminishing ratio to the still more rapidly expanding horizon of our knowledge."

The experience of the past, then, whilst constantly encouraging us to hope for the future, naturally leads to fresh researches and to new applications. Whilst in the few preceding pages we at first pointed out, in very general terms, how enormous had been our advances, of late years, in respect to mining and metallurgy, we considered it desirable that all our readers, but especially those engaged in the various occupations referred to in this chapter, should have a bird's-eye, and very imperfect, view of some of the fields still open for investigation. It generally happens in this, as in every other branch of science, that a man opens out for himself a special field for research, from which a certain amount of persistency of character, essential to success in science, will not permit him to diverge to any great extent. Occasionally some collateral subject may come under his notice, but still *the* subject is his main pursuit. Thus we have had electricity built up, in all its branches, by Faraday; geology by a host of eminent men—Lyell, Ansted, Murchison, and others, dead and living, too numerous to name: we have had our Newton, Leibnitz, Herschel, and others, in connection with astronomy; and so on with each branch of science. But, in all these cases, the penetrative intellect of those chief in such pursuits has rarely been bent to the applications that may result, or have resulted, from their abstract researches. Such applications are generally made by persons of an entirely different class of mind, who, whilst very frequently possessing much practical knowledge, have not yet had the benefit of long scientific training, and the consequent drill of mind and hand desirable for extended investigations of the class to which we now refer. This circumstance has been associated, up to very recently, with every branch of our arts and manufactures. But this error is rapidly being amended. In most of our large establishments, whether for the smelting of metals or their manufacture; in our dyeing, bleaching, chemical, and other works, the services of men capable of originating new researches, and of remedying or meeting difficulties of a practical nature as they arise, are secured. It is from such persons we may expect to receive, in the course of time, a solution of many of the problems which we have, in

the previous pages, mentioned as yet unsolved. First, trained to close and accurate scientific investigation in the laboratory, and acquainted with the previous researches of others that are daily in contact, in the factory or workshop, with processes as ordinarily carried on, they can detect waste, error, or novelty; prevent the two first, and seize the latter, to the advantage, not only of the firm with whom they are engaged, but also, eventually, to that of the whole trade, and consequently to the nation, because when one branch of manufacture prospers, it spreads, wave-like, its influence on all others, directly or indirectly related to it. We have seen remarkable instances of this in many branches of metallurgical and other departments of manufacture. One instance is directly connected with this subject, as seen in the application of science to iron manufacture, by Sir H. Bessemer, whose new process has not only been of great pecuniary advantage to himself, but has become of national, nay, world-wide importance. Equally might we instance the first patentee of the method of obtaining paraffin; and that of getting aniline colours from coal-tar. But such cases are too numerous to recapitulate. They have one great and encouraging effect; for they prove that "knowledge is power;" and that he who possesses that power, may wield it, judiciously applied, to the benefit of himself, of the society in which he moves, and to that of the nation of which he is a citizen.

CHAPTER VI.

QUARRYING OF BUILDING STONE, ETC.

IN the preceding chapters, so far as mining is concerned, we have solely dealt with coal and metals, which, generally, are found at great depths from the earth's surface. But quarrying, although carried on near the surface of the earth, is really a species of mining. Many operations, such as pumping, lifting the material, &c., are the same as in coal and metal mining, and the apparatus already described for such purposes, is, to a large extent, required in stone quarrying. Hence we have deemed it convenient to introduce the subject here rather than defer it to another chapter, where it would there have, as far as the arrangement of this work is concerned, but little relation to the operations already described.

The kinds of stone employed in masonry are numerous. Granite, one of the hardest of all, is generally blasted with gunpowder or dynamite, as a means of moving it from its bed; and the detached masses are roughly hewn into shape on the spot with small pickaxes. Aberdeen and Peterhead granite is generally separated from the rocks by cutting a long deep furrow or fissure, placing strong iron wedges at intervals in this fissure, and striking the wedges with heavy hammers till the mass splits. In some cases a curious mode is adopted of separating masses of stone; a fissure is made in the surface, and in this fissure dry wooden wedges are placed; water is poured on the wedges, the wood of which they are formed swells by the absorption, and the stone is rent by this swelling or pressure.

For general purpose, some of the varieties of *limestone* are much more employed for building than granite, or the harder rocks, as being more easily workable. Bath-stone, for instance, of which nearly all the buildings in Bath are constructed, is so soft as to be easily cut with a saw, like a piece of timber, and it is capable of being carved into ornamental forms with great facility; but it is very seriously acted on by alternation of weather, insomuch that it crumbles and decays in the course of (comparatively) a few years. The restorations of Henry VII.'s chapel at Westminster Abbey were unfortunately made with this stone, and they soon became in a state of decay.

The relative values of different kinds of building stones had not been systematically inquired into until a comparatively recent period, when Sir Charles Barry, architect of the new Houses of Parliament, suggested the appointment of a Commission, whose duty it would be to examine into the durability and other qualities of stone for building. The Commissioners visited more than a hundred quarries, and submitted specimens of stone to Professors Daniell and Wheatstone, for mechanical and chemical examination. They inspected 175 edifices, including abbeys, cathedrals, churches, towers, castles, and other buildings; with a view of determining how far any particular degree of preservation or of decay depended on the use of any particular kind of stone. They found that limestone employed at Oxford had greatly decayed; as also magnesian limestone at York, and sandstone in Derby and Newcastle. In a report published by them, they gave the most minute account of all available particulars concerning each quarry—such as the name and locality, the names of the freeholder or agent,

and the quarryman, the mineral designation of the stone, its colour and specific gravity, the depth of workable stone, a description of the beds and the size of the obtainable blocks, the price at the quarry, the cost of conveyance to London, the cost of working it, and the evidence of its durability or otherwise in buildings already constructed. The two professors in London tested numerous varieties of stone, in every way deemed likely to bear upon the object in view; and the result of the whole inquiry was a recommendation, on the part of the Commissioners, that the stone employed in building the new Houses of Parliament should be the magnesian limestone or dolomite, obtained from a quarry at Bolsover Moor, in Derbyshire.

Whatever may be said of the moderns, the ancients certainly appear to have known how to select their building-stone with judgment, in many cases at least; for there are specimens still existing which must have been constructed at least three thousand years ago. It is only fair, however, to bear in mind, that as we do not know what proportion the decayed and the preserved specimens of masonry bear to each other, we cannot say how far credit is due to the judgment of ancient builders in this respect. The pyramids of Egypt are a mighty example both of vastness and of durability, and must ever be regarded among the most wonderful specimens of masonry. The kind of stone employed by the ancients was not, however, the only point of interest in respect to the construction of their stone walls and buildings; the mode of shaping and connecting the stones was also in many instances remarkable. The still remaining walls of Pompeii, and of other towns in Italy and in Greece, illustrate some of the rudest modes in which stones are put together. Two very early styles of masonry, called the Cyclopean and the Etruscan, are met with in Greece and in Italy; and to the latter of these a large portion of the walls of Pompeii belonged. With respect to the terms Cyclops and Cyclopean, they relate to mythological matters, which have become strangely mixed up with history in the narrations of classical writers. Many of the walls of ancient fortified towns are said to have been built by a mighty people called the Cyclops; who these Cyclops are meant to represent, or by whom the walls were really built, are questions not easily answered at the present day; but it is known that many walls, such as those at Tiryns and Mycenæ, which must have been built at least three thousand years ago, still remain solid in construction, massively grand in their parts, and apparently scarcely injured by the lapse of so many ages.

The construction of the Cyclopean walls has been aptly compared to that of the dry stone walls which serve for fences in many parts of the north of England. Such fences are made where stone is plentiful, and where irregular masses, heaped together without much order, form a very efficient fence, and at the same time help to clear away the stony ground of fragments which encumber it. So, likewise, is the Cyclopean masonry; the wall is built of huge polygonal masses of rock piled up on each other, without any artificial adaptation of their sides, but having the interstices at the angles filled up with small stones. Such walls are used at Tiryns, Mycenæ, and other places in Greece, as a fortification to enclose the Acropolis, or elevated spot containing a palace, a fortress, and a temple. The space thus enclosed at Tiryns is two hundred and twenty yards in length, by sixty in breadth. The walls consist chiefly of rude unwrought masonry; but there are some galleries formed of stones, which seems to have been hewn by the chisel to a definite contour.

The enclosure at Mycenæ is larger than that at Tiryns. The greater part of the walls consists of polygonal or variously-shaped blocks, well fitted into each other in some instances, but in others exceedingly rude of construction. It is observable that there is a great difference between two kinds of Cyclopean masonry; in the one, the large blocks seem to have been selected without any regard to shape, and to have been placed one upon another without much order or system, the interstices being afterwards filled in with smaller stones; while in the other the blocks are chosen with such reference to size and shape, that the convexities and protuberances of the one may fit into the concavities and hollows of the other. A later style, but still Cyclopean in being without the use of mortar, consists in having the stones ranged in pretty nearly horizontal courses, though the transverse joints are irregular instead of vertical. This more regular style, however, is found rather in Etruria (an ancient name for a part of Italy) than in Greece. In the remains of an ancient Etruscan city near the river Ombrone, the walls are a mile and two-thirds in circumference, built of enormous masses of travertine or coarse limestone, having the exterior surface worked to an even plane; many of the blocks are fourteen or fifteen feet long, and of enormous thickness. In the ruins of another of the Etruscan towns the walls are built of solid blocks of pure white marble.

At Pompeii, wherever the ancient walls still exist, they consist of courses of stone laid rudely horizontal, but with the joints inclined to the perpendicular. Some of the stones are dovetailed into each other. On the north and north-east, the ramparts consisted of an earthern terrace fourteen feet wide, walled and counter-walled, which was ascended from the city by flights of steps broad enough for several men abreast. The greater part of the walls are built of lava, and the rest of course limestone; all the stones being well joined, but without mortar.

Some of the various kinds of masonry above alluded to are illustrated by representations from ancient walls still existing, in the following cuts (Figs. 154 and 155).

The position of the layers of building-stone in the various quarries, and the commercial features presented by the working and disposing of the stone, differ in different districts; but it may be sufficient for the present, so far as our own country is concerned, to describe the Portland Quarries, as a type of all generally.

The Isle of Portland, from which such a vast quantity of building-stone is obtained, is situated near the coast of Dorsetshire, with which it is connected by a narrow pebbly belt called the Chesil Bank; the two being so oddly shaped as to cause Portland to be compared to a "breast of mutton suspended to the mainland by a

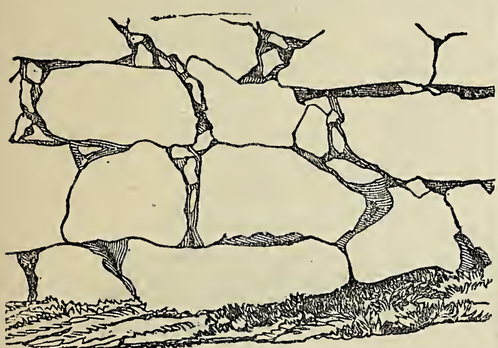


Fig. 154.—Ancient Masonry, Greece.

string." The isle itself, which is about four miles long by one and a half broad, consists of a rock of freestone, the highest point of which is nearly five hundred feet above the level of the sea. Near the western cliffs are the quarries from whence the stone is obtained. These quarries belong to the Crown as lord of the

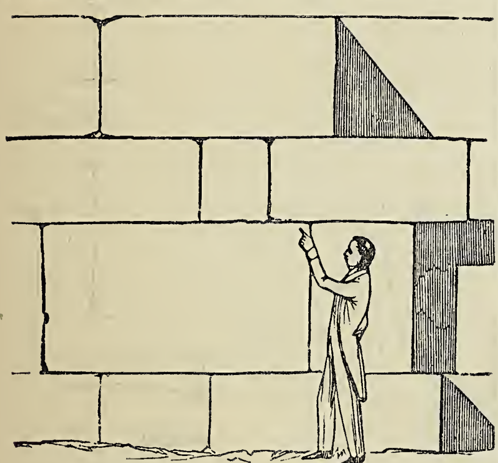


Fig. 155.—Ancient Masonry, Italy.

manor, but are let out to tenants under various forms of tenure, or worked by convicts. The management of each quarry is intrusted to an agent, who has under him a foreman and a company of six quarrymen and two boys. The agent and the foreman are paid a fixed salary, but the earnings of the quarrymen depend on the quantity of stone raised—a system similar to that adopted in mining districts.

The position which the Portland freestone occupies with respect to other geological strata, may be seen by an inspection of Fig. 156. There is first several feet in depth of the surface-soil; then sixteen feet of a kind of grit-stone, called by the quarrymen "turf-layer;" then nine feet of roach-stone; and then the good Portland stone, which forms a compact horizontal bed about eight feet in thickness. Beneath this are layers of clay, black marl, clay mixed with flints, and other mineral beds. The work which the quarrymen have to perform, therefore, is to remove the surface-soil, the sixteen feet of turf-layer, and the nine feet of roach-stone, before they can get to the Portland stone at all. All this is a work of great labour. First, the surface-soil and rubbish are dug up and wheeled away in barrows to fallow-fields in the neighbourhood. The "turf-layer" is harder, and requires the aid of wedges and other contrivances to break it into portable lumps; these pieces are thrown into carts, and the carts, drawn by seven or more horses, convey their load either where it may be thrown into the sea, or piled up in heaps at a distance. The roach-stone is not less hard and obdurate in its character, and requires blasting as a means of separating it into convenient masses. A circular hole about five feet deep by three inches wide, is drilled in the rock, and into this hole is rammed a portion of gunpowder or other explosive, connected with a train on the outside. The train being fired, the powder explodes, and the rock becomes rent for several yards around the hole with vertical fissures. The masses of stone between these rents sometimes weigh fifty tons each; and to remove these is a long and laborious process. Rollers and jacks, worked by the hands of the quarrymen, are the only means adopted for removing them. Three of the jacks are placed against the mass to be removed, and the men commence to heave round the winches, cheering each other by a shrill cry of "High, boys, high!" It is only by the most minute shades of distance that the huge block can be moved at each effort; but it *is* moved, and the labour has been characterised as one of the most severe to which any body of men are ever subjected.

When all the superincumbent strata are thus cleared away, the quarrying of the real Portland stone (Fig. 157) commences. The bed of Portland stone is found to be fissured in various directions; and these fissures divide it into masses which facilitate its removal. By wedges and other contrivances the masses are loosened, and are by degrees removed out into an open spot of ground. Here a sort of council is held among the men; each piece of stone is examined as to its size and shape, to determine whether it is best fitted to make a shaft, a baluster, a pier-stone, or other form required by the builder, and when the decision is arrived at, the mass is brought to a rude approximation to that form by a heavy pick called a "kivel." The stone is weighed, and the weight marked on it, together with the name or monogram of the proprietor. When the stone is ready, it is lifted on to a rude sort of cart or truck with solid wooden wheels,

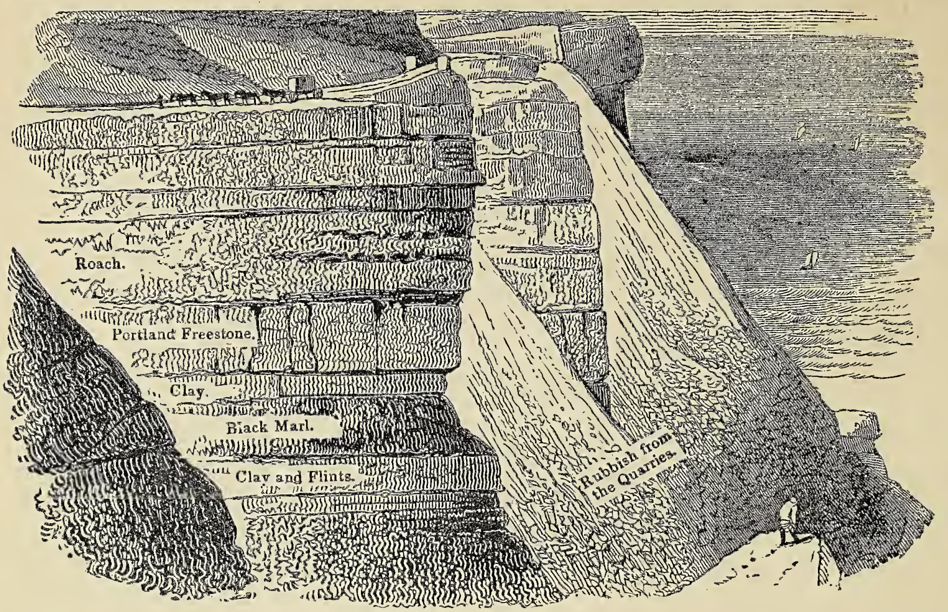


Fig. 156.—Strata at the Portland Quarries.

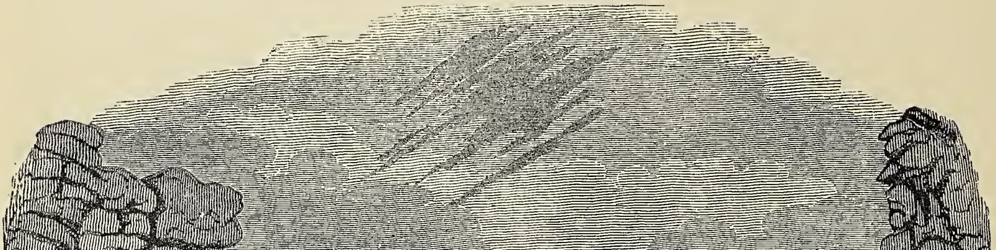


Fig. 157.—Portland Quarries.

and drawn by several horses to a central station, whence it is removed to the wharf for shipment.

Steam machinery has made its inroads on stone-quarrying as in most other branches of modern industry. In the following cut is represented a steam derrick for raising stone from quarries.

We are indebted to the constructors, Messrs. Appleby and Co., of London, &c., for the illustration and the following description written by Mr. C. J. Appleby :—

meter by 10 inches stroke, with link reversing motions; the lifting gear is single and double purchase, and the slewing is transmitted from the engine shaft to the first motion shaft by reversing friction cones, admitting of its use when lifting or lowering, and without stopping or reversing the engines. The boiler is placed behind the driver, and is carried on a wrought-iron water-tank, from which the feed water from the boiler is supplied, the feed pump being worked from the crank shaft; the back end of the tank is

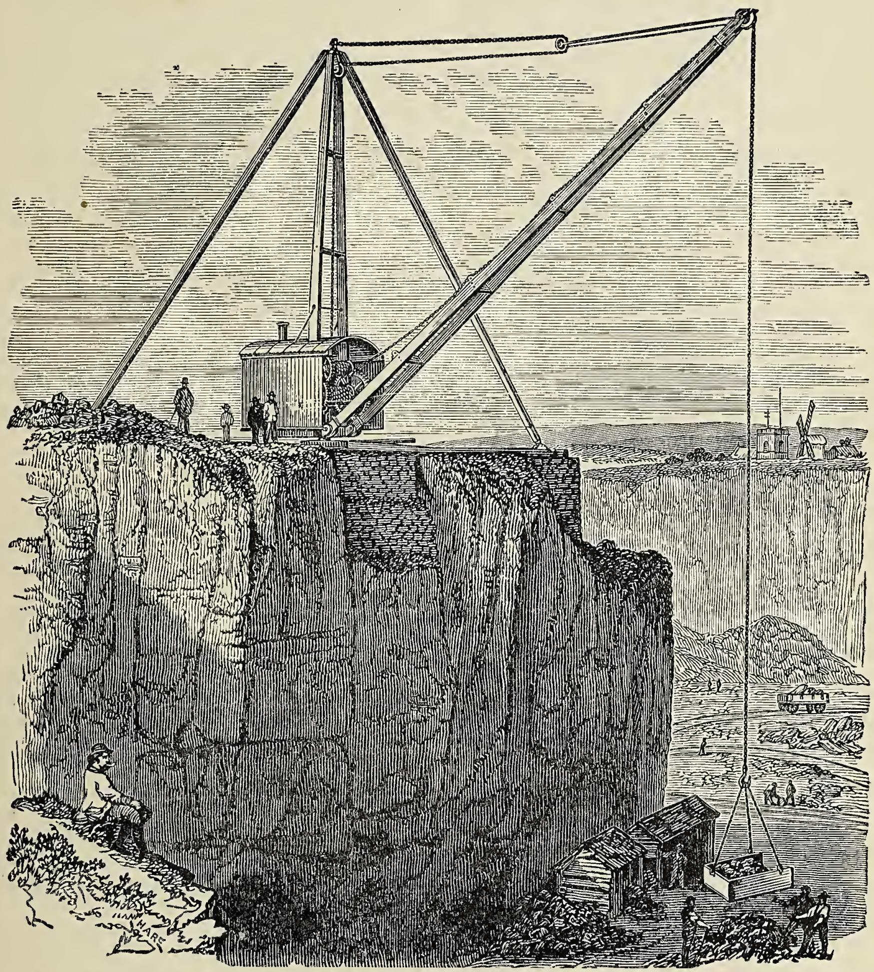


Fig. 158.—Steam Derrick for raising stone from deep quarries.

"The illustration is engraved from a photograph of a derrick designed and constructed for the Mount Sorrel Granite Company in Leicestershire. It is proportioned to lift loads of ten tons with a sweep of 50 feet, and stands on the edge of the quarries, which are upwards of 100 feet deep, and has given excellent results. It is selected for illustration and description as being a recent, and perhaps, one of the best examples of this most useful type of crane.

"The derrick has a pair of engines $7\frac{1}{2}$ in. dia-

stayed to the mast; the boiler is fitted with all the usual mountings, and the whole is protected by a corrugated iron house. The timbers are of the best pitch pine, the jib is double, and the back guys are trussed to the sleepers."

In connection with the general quality, characters, and sources of modern building stones, we shall quote from the *Circle of the Sciences* some remarks by Professor Ansted, who deservedly stands high as an authority in such matters.

Nature of Materials.—These include a large number of natural substances, which, from their hardness and tenacity, can be used for purposes of construction without any further preparation than that of cutting them into convenient forms.

Of stones, properly so called, capable of being adopted for construction, there are two classes —one including all those commonly used in squared blocks, and in the solid, often existing in large quantity, and obtainable at moderate cost, but having no very special tendency to split or work in any particular direction; and the other, such minerals as are chiefly employed for roofing and paving, which split readily into very thin portions, as slates, or are capable of being worked into thicker slabs and flag-stones, having parallel faces.

The building-stones that are best adapted for general use in any particular district, are naturally those that combine the greatest amount of durability with moderate cost; and as the cost of transport to any distance must be a serious item in the expense, the nearest will be, *cæteris paribus*, the best. But the durability, and therefore the ultimate economy on a large scale, is by no means easy to determine without careful and minute investigation or long experience; and thus a number of inquiries are necessary in reference to those materials which, being the nearest at hand, would first be suggested for use. Questions concerning building material include a large number of geological considerations, both as to the nature of the stone, the mode in which it lies in the bed, the probable result of the exposure to which it will be subject, and the probability, or otherwise, of sufficiently large quantities being obtainable to justify the opening of a quarry.

Valuable Qualities of Building-Stone.—The ordinary building-stones are either freestone or granites; the former being usually bedded, and their value depending a good deal on the conditions in which they are presented for use. The latter are not usually bedded, but are naturally broken into tolerably regular forms by joints. Joints also exist in stratified rocks, and greatly assist the quarryman. The points to which attention should chiefly be directed, are —(1.) With regard to position and quantity—that the stone be well and conveniently placed; abundant; and accessible both for quarrying and removal. (2.) As to the nature of the material—that it be neither too hard nor unnecessarily heavy; workable at moderate cost; able to bear a heavy superincumbent weight without crushing; and sufficiently durable under the exposure to which it is liable. These are matters independent of geological age, but on which many results of geological inquiry throw great light.

The methods of investigation, usually adopted with regard to stones submitted for inquiry, are not very numerous or complicated, and may be here briefly referred to. It must be remembered that the climatal and atmospheric changes to which stones are to be exposed, introduce by far the most numerous and important causes of disintegration and decomposition; and also that, without some actual experience on the spot, the exact effect of atmospheric action can hardly be discovered. The material, composition, and texture of a stone, will, however, greatly influence the nature and extent of all destructive changes to which it can be exposed. When, then, a stone is submitted for trial, the first things to be determined are its *mineral character* and *chemical composition*, so far at least as to discover what are its chief ingredients, and whether it contains any that are usually subject to decomposition. As an example of the importance of this, it may be enough to mention, that sandstones, limestones, and granites behave in a manner totally different under exactly similar exposure; and that the presence even of an extremely small per-centage of some of the alkalies in the two latter is injurious in the highest degree, although other alkaline bases seem to have little effect. Having determined the nature of the stone, its *hardness* (both in the quarry and after exposure) and its *brittleness*—two very different things—should next be made out in relation to some admitted standard. The best standard will generally be the cost of working. The *weight* is a quality also important, and more easily determinable, and is usually estimated by stating the average per cubic foot; but it may also be taken more accurately from the specific gravity. As, however, it is difficult to get a precisely average sample of small size, the former is the more practical as well as the easier method.

Dr. Ansted then gives the various modes of testing the power of absorbing moisture, a subject of which we have not space to enter into.

Sandstones.—The sandstones or grits usually consist of grains of sand, or small pebbles, cemented together either by silica, the salts of lime and magnesia, oxide of iron, clay, or an admixture of two or more of these. When the pebbles are large, the stone is called a conglomerate, or pudding-stone; and when the cement is hard, and the pebbles entirely quartzy, the whole wearing into a rough surface, or when there are cells or empty spaces also, insuring a rough surface, the variety is useful for grinding, and becomes a *grindstone*, or *millstone*. The finest of these latter are obtained from Yorkshire, France, and America, and have special uses; but they are different in no essential respect from the building-stones or flag-stones, of which they form part. The best hard sandstones splitting freely, and not used as grindstones, are greatly valued for pavements, and will be again alluded to when describing flags.

The building materials of this kind used in England are numerous, and include some of great value. From the carboniferous rocks at Craigleith, near Edinburgh, is obtained one of the best and most durable stones known. Its colour is lightish grey; its composition upwards of 98 per cent. silica, with 1 per cent. carbonate of lime, and a little carbon; its cementing medium is silica; its weight is moderate, amounting to 145 lbs. per cubic foot; the quantity obtainable is indefinitely large, and it can be got in blocks of any required length

and breadth, up to ten feet thick. It is worked in quarries, in which there are many acres of stone laid bare, and several more known to exist; the total depth of stone proved in the quarries being 250 feet. It takes upwards of 4,000 lbs. on the square inch to crack, and nearly 8,000 to crush a fair average sample; and exposed to disintegration by Brard's process, one three-fifths of a grain are lost. It has been greatly used in Edinburgh for all kinds of buildings. In London it is valued for steps and landings, and its cost is moderate.

Other valuable sandstones in England are obtained from the millstone grit, also a part of the carboniferous series. Those quarried at Darley Dale, near Matlock, in Derbyshire, and in various parts of the same county, and in Yorkshire, are remarkably good, and much used. Samples of the first named (Darley Dale) have been found to resist pressure, under Bramah's press, to a remarkable extent, not cracking until the weight amounted to eleven tons on the square inch, and only crushing at fifteen tons. The millstone and coal grits are particularly valuable for grindstones and flags.

Some good stone is obtained from the new red sandstone, both in England and Scotland—especially the latter. The Storton quarries at Birkenhead, the Mansfield quarries in Nottinghamshire (see Fig. 159, representing Nottingham Castle, built on the new red sandstone), and some others, yield a serviceable, cheap, and good-looking stone. In Scotland, that quarried upon Sir William Jardine's property in Dumfriesshire, the celebrated Corn-Cockle Muir, is also of good and uniform texture, and of even tints. It has worn well where tried, and stands exposure to the atmosphere of that part of Scotland. Spedlings Castle, in 1508, and the mansion of Jardine Hall, in 1814, were built of it; and the chiselled margins of the pillars and cornices of the latter are still as sharp as when first carved. This stone can be furnished at a moderate rate, and in blocks of any size.

Excellent, hard, durable sandstones are obtained from the Wealden beds quarried at Tilgate, in Sussex; and the Kentish rag is a material well known, and remarkable for its durability under the worst exposure. This is from the beds of the lower greensand.

Limestones.—The limestones used as building material are chiefly from the carboniferous limestone and oolites, though the older rocks come into local use, and the chalk has been employed in the interior of some of our cathedrals for decorative work. The carboniferous limestone is so far altered by metamorphic action as to bear a polish and partake of the character of marble; and is, therefore, more frequently met with as an ornamental stone than for ordinary constructive purposes. The oolites thus remain as the principal sources of building-stone; and, being abundant, conveniently placed for carriage, easily worked, obtainable in large slabs of good colour, and generally durable, they are very widely employed throughout the middle and south of England, in all the principal towns, as well as in the metropolis. Of the whole number, the Bath and Portland oolites are the best known, and those which are most widely employed; but several others enter largely into use. The Northamptonshire oolites are better than those from Bath, and cheaper than the Portland stone; while the Oxfordshire stones, and those from adjacent counties, although extremely convenient, and much used locally, are of indifferent quality. The following are from English quarries, sold in London:—Anston stone; Bath stone, from Farleigh and Coombe, Down, Box, and Corsham; and Portland stone, blocks, roach, &c., from Waycraft, Westcliff, and Bill quarries. Besides these, there are the Ketton and Barnack stones, both admirable in their way; and Ancaster (Lincolnshire), greatly used in some of the fine churches of the east of England. These are all, to a certain extent, laminated, having been deposited in beds; but they are so far changed or metamorphic as to have assumed a peculiar character, from which their name *oolite* is derived, from the Greek *oon*, an egg, and *lithos*, a stone. They consist, more or less completely, of rounded particles, like the hard roe of a fish, mixed with shells and fragments of shells, often crystalline.

Bath stone varies a good deal in colour and quality; it is, however, usually of a warm cream tint, often streaked. It is fine-grained, and very soft in the bed; but hardens when taken out of the quarry. On exposure to the weather in London and elsewhere in towns, it very rapidly injures, in consequence of the facility with which it absorbs moisture and impurities existing in the atmosphere. The composition, on analysis, shows about 94½ per cent. of carbonate of lime, with 2½ per cent. of carbonate of magnesia, and no silica. It is capable of absorbing nearly one-third of its bulk of water (2½ gallons to the cubic foot). It weighs about 116 lbs. to the cubic foot. It disintegrates to the extent of ten grains by Brard's process. It can be obtained in large blocks, to almost any extent, at a cost of not more than sixpence per foot, cube, at the quarry; and, in cohesive power, it has been found that good specimens bear a pressure of 1,250 lbs. before they crack, and do not break till they are subject to 1,500 lbs. on the square inch. The advantages of Bath stone are numerous and manifest; but the objections to it are also serious. It appears rarely to have been subject to exposure without suffering severely, and, in some cases, the whole substance is disintegrated.

Portland stone (already described in respect to its quarrying at page 203), offers a remarkable contrast to Bath stone in many respects, although both are oolitic limestones. The former is much whiter than the latter, much harder, and much stronger; but it is also heavier and dearer. Its colour is white, grayish white, and whitish brown. It consists of 9·52 per cent. carbonate of lime, and 1·2 per cent. carbonate of magnesia. It weighs 145 lbs. to the cubic foot. It disintegrates only 2·7 grains under Brard's method; cracks at 2,000 lbs.; and crushes at 4,000 lbs. But its cost is very much greater than that of any kind of Bath stone; although

for slabs, steps, landings, and other purposes where durability is important, it is often used. Of other stones, Ketton resembles Bath stone in composition; but it weathers very much less. It is about intermediate in weight between Bath and Portland; absorbs a great deal of water, and is extremely remarkable for its high cohesive power. Its disintegration is small. Barnack, with many resemblances to Ketton, is far less durable, as determined by Brard's process. It is more shelly in its composition, but has stood well in numerous buildings.

Those magnesian limestones which are valuable for building purposes, consist of nearly equal parts of carbonate of lime and carbonate of magnesia, in a state of perfect combination and of crystalline texture. The colour is peculiar and agreeable, being accompanied by a singular pearly lustre. The specific gravity is high, the best stone weighing 150 lbs. to the cubic foot. The cohesive power is very great, specimens of the stones cracking at 5,000 and crushing at 8,000 lbs. to the square inch of surface. The price in London is moderate; and the stones of this kind work easily, and are generally durable. They have been used for the exterior of the palace at Westminster, but have suffered much from the action of the weather.

Fig. 159.—Nottingham Castle (New Red Sandstone).

Softer stones, and even chalk, are occasionally employed for internal work; but these are too easily injured to bear any amount of atmospheric exposure to our climate. Besides the materials commonly adopted for internal work in public buildings, there are impure marbles, both from the oolite and Wealden series of rocks, formerly a good deal admired for small columns in Gothic architecture. Of this kind are the Purbeck and Petworth marbles, and the Forest marble. They easily injure on exposure, and, in time, lose their polished surface, owing to the inequalities that exist in their composition.

The foreign building limestones used in England are few, but not unimportant. The best known are the even-grained cream-coloured oolitic stones from the neighbourhood of Caen, in Normandy, formerly much employed in the construction of many of our cathedrals. These have always, and with reason, enjoyed a high reputation, and are considered the best material for internal use in the Gothic buildings of the present day. The quarries of Allemagne (near Caen) yield a very good quality of stone.

Granite.—The granites used in building are obtained from Cornwall and Scotland; but others, of excellent quality, exist in Wales; and even in Leicestershire, in the middle of England. Their use is confined chiefly to the more costly constructions, except in the immediate vicinity of the quarries, as the stone is far too hard to be easily chiselled into convenient forms, even of the simpler kinds. For ornamental purposes, and buildings richly decorated, it is rarely that this material is largely employed.

Many of the granites are, however, so remarkable for durability, that they are used with great advantage for bridges, docks, piers, and public monuments. The large-grained Cornish varieties used in London Bridge; the fine polished columns from Peterhead, near Aberdeen, in the King's Library, at the British Museum; many other interesting and excellent specimens in England; and the noble monuments of antiquity preserved in Egypt, or transported to the museums of Europe—all serve to prove the applicability of granite for certain purposes. The porphyry vases of Sweden and Russia, and other ornamental objects manufactured in this material, may be regarded as proofs of successful ingenuity rather than illustrations of the real uses of the stone.

Fig. 160 represents the Aiguille de Dru, a granite mass occurring in the Mont Blanc range of mountains.

Marbles.—Various kinds of stone may be included under this general head. True marble consists of crystalline carbonate of lime, either almost pure, in which case the colour is white, or combined with oxide of iron and other impurities, communicating colour. Other substances are alabaster (sulphate of lime), serpentine (silicate of lime and magnesia), malachite (carbonate of copper), fluor, spar, &c.

Marble, properly so called, is sometimes crystallised in a saccharoidal manner, having the fracture of loaf-sugar, or foliated, and with a peculiarly even grain. Such kinds are used by the sculptor, and are called statuary marbles. They are found in Greece (Parian marble), in Italy (Carrara marble), and occasionally in other countries of Europe, but in smaller quantities. They abound in some parts of India. The chief source of the present supply is from Carrara, in Tuscany.

The coloured marbles are far more common

Fig. 160.—View of the Aiguille de Dru, a Granite Rock.

Fig. 161.—View of Skiddaw (a Slate Mountain).

and are infinitely varied in tint and in the mode of venation in which the colour chiefly appears. They are also very widely distributed in most countries where limestone occurs, in association with, or near to, those rocks technically called igneous or metamorphic—in fact, wherever crystalline forces have been at work. Thus, in our own country, the marbles of Derbyshire (black, gray, red, &c.) and of Devonshire are well known, and belong to rocks of the older (Palæozoic) period, chiefly of the carboniferous series, and the rocks immediately underlying; the marbles of Ireland are not less beautiful and abundant, though less known. In Belgium, France (especially in the Pyrenees), Spain, Portugal, and many parts of Germany; in Turkey, Egypt, India, China, and other parts of the east, and in America, these decorative mineral substances are widely distributed; while Italy and Greece have been celebrated, from the earliest times, for the exquisite specimens of such material they have lavishly supplied to their intelligent and ingenious populations. The most celebrated and valuable of the ancient marbles are the *rosso antico* (red), *nero antico* (black), *giallo antico* (yellow), and *verde antico* (green). The red and green are not equalled by any now in use; but the black marble of Derbyshire, and the Sienna marbles, rival the black and yellow kinds. There is also, in Derbyshire, a small quantity of a very fine red marble.

Slates, Slabs, and Flagstones.—Slate and slate slabs are argillaceous rocks in a peculiar state of partial crystallisation, possessed of the property of cleavage, or splitting in some one direction quite independently of the original bedding. Other slabs and flagstones are usually silicious rock, combined with more or less argillaceous or calcareous matter, and splitting into tabular masses of various size and thickness in the original planes of bedding or stratification. The best slates are obtained from various parts of North Wales, near the coast; from Delabole, Tintagel, and elsewhere on the north coast of Cornwall; from various parts of Cumberland; and from the west coast of Scotland, generally from quarries of great magnitude. The best slate slabs are from Wales. The finest slabs and flagstones (not argillaceous) are from Yorkshire and Caithness; but some of the Portland stones (limestones), of the best quality, are preferred for internal use, as for steps and landings. Excellent foreign slates are obtained in France, chiefly from near Angers, and in Brittany; in Belgium from the Ardennes; in western Germany from the duchy of Nassau; and in the east of Europe from other places. Slates and slabs are also found in America.

It is not usually the case to find slates and slabs in good condition near the surface, where long exposure to the weather has usually disintegrated, and even destroyed the texture, and often, by partial hardening, obliterated or obscured the cleavage. As it is, however, entirely from the superficial rock, and its geological condition, that a judgment must be formed, a certain amount of experience, combined with a knowledge of the material, enable the geologist to judge well of the chance of a valuable quarry. Uniformity of texture and condition of the rock for considerable distances; the nature and condition of the cleavage; the direction of the cleavage planes; the nature of the small veins of other material pervading the slate (of which there are always many); the presence or absence of iron pyrites; the direction and magnitude of the joints—these are the chief points concerning which careful investigation is necessary. But any or all of these are altogether insufficient to communicate a market value to a property, unless the essential point of cheap and ready conveyance to a large market can be secured, and the quarries are so situated that the waste can be disposed of, and the valuable part of the slate laid bare without great expense.

There are varieties of colour, of texture, and of hardness, which affect the value of slates. The common colours are green and purple, both of which may be good. The hardness should be considerable, without interfering with the fissile character of the material, and the grain should be fine. If large slates or slabs can be cut, this of course adds greatly to the value of the quarry.

The slate quarries in various parts of England, Wales, and Scotland, are objects of great interest, if only in a picturesque point of view; but they are of a magnitude really important in an economic sense. The Delabole quarry, for example, in Cornwall, is opened for some hundred yards in length, and has a width of upwards of a hundred yards, and a depth nearly as considerable. The Ballahulish quarries, in Scotland, are worked in three terraces facing the west, the total height of the workings being 216 feet.

But the great Penrhyn quarry, close to which are the Llanberris quarries, and others, are far more remarkable and valuable; in the Bangor quarry, in the extreme west of Carnarvonshire, the band of slate (or vein, as it is locally called) is considered to run twenty miles, with a breadth of 500 yards. Where long exposed the slate is usually much harder than is convenient or profitable to work, and the valleys yield the best and most valuable portions. The one quarry of Penrhyn, belonging to Colonel Pennant, has been opened about a century, and is worked in twelve galleries of horse-shoe form, one above another. Each gallery is forty feet high, the highest being 500 feet above the lowest; but the uppermost slates are of inferior quality.

Fig. 161 gives an illustration of Skiddaw, a slate mountain.

Flagstones.—Of the slabs and flags used for paving, cisterns, and various other purposes, those from Festiniog (North Wales) are remarkable for their large size, even grain, and great beauty. Those from Valencia (west coast of Ireland) are also extremely large, and of excellent quality.

The Yorkshire flags are fine-grained, laminated sand-stones, from the millstone grit formation, cleaving into slabs of large size, whose thickness is from two or three, up to eight inches. They

are remarkable for their extreme hardness and toughness. Of the beds yielding these flags, there are no less than fifty well known, and these are worked in upwards of 100 quarries around the towns of Leeds, Bradford, Wakefield, and Halifax. The Caithness flags are from the much older beds of the old red sandstone, and are dark-coloured bituminous schists, slightly micaceous and calcareous. They, like the Yorkshire stones, are valuable from their great toughness and durability. They are not obtained in slabs so large as those found in Yorkshire.

The limestones of the carboniferous, and even of the silurian period, yield some good flags; and a remarkable fissile bed of the lower oolitic series is locally much used for slating, under the name of Stonesfield slate, and Colley Weston slate. Coarse, easily splitting limestones are extensively quarried in Oxfordshire, Northamptonshire, and some adjacent counties, and are of some value where slates are costly.

Cements.—These are of various kinds, extremely distinct, and having different bases. The one kind, depending for its peculiar properties on sulphate of lime, with which it is made, may be conveniently designated as *plasters;* the other, in which carbonate of lime is the essential combining substance, includes mortar and hydraulic limes; and for this the name *cement* may be adopted. We may first consider the cements as being the material of greatest importance in manufactures.

The commonest of all cements used to attach bricks to each other is called *mortar*, and is prepared by first making *quicklime* (which is done by calcining chalk or limestone in a kiln until it becomes decomposed, parting with its carbonic acid gas, and passing into the state of a white or gray powdery material, greedily absorbing water with the evolution of much heat), and then making a paste by mixing the quicklime with sufficient water, and about two or three times its own weight of sharp sand, or gravel. This mixture dries slowly; but, when dry, becomes extremely hard, and firmly attaches itself to the foreign substances in contact with which it is placed. When a layer of it is placed between bricks or stone, it cements them firmly together.

It is often desirable to obtain a cement that shall dry more rapidly than common mortar, and under less favourable circumstances for dryness; and it is found that when a certain proportion of clay has been present, mixed with the limestone before burning (whether naturally or by preparation), and the calcination is carefully conducted, and not carried too far, the resulting lime, when mixed with a proper quantity of water, sets rapidly in a damp atmosphere, and even under water. Such a limestone is found in the lias, in the London clay, and in various other rocks; and the resulting lime is called *hydraulic lime*, or *hydraulic cement*. The simplest and strongest of such cements is obtained when from 10 to 25 per cent. of the stone consists of silicate of alumina, and the rest is carbonate of lime. The larger the proportion of clay in the stone, *cœteris paribus*, the more rapidly the cement becomes solid, the hardening being complete in two or three days, when the proportion amounts to 25 per cent., and taking three weeks when only 10 per cent. Much depends (especially in artificial admixtures) on the minute division and perfect admixture of the foreign particles.

The kind of cement known as *Roman*, or *Parker's*, is made from nodules of calcareous matter obtained from the beds of the London clay at Sheppey and Harwich; from the Oxford and Kimmeridge clays, near Weymouth; from the lias of Whitby; and from similar deposits elsewhere. In all these cases the admixture of clay with the carbonate of lime is natural, and varies considerably in different samples. *Medina*, *Atkinson's*, *Mulgrave*, &c., are names given to cements of this kind, offering no essential difference in their nature.

Portland Cement is made from carbonate of lime, mixed with great care, in definite proportions, with the muddy deposits of rivers running over clay and chalk. The whole of the materials are carefully pounded together under water, and are afterwards dried and burnt. From various experiments, it appears that when well made, in good condition, and properly used, the value of Portland cement is much greater than that of the natural kinds (Roman); but in practice on a large scale, different casks, even from the same maker, and made at the same time, vary so much, that it is not safe to trust it to a much greater strain than would be given to Roman. Good Roman cement will bear a strain of nearly sixty pounds to the square inch; but some specimens will break with twenty pounds. Good Portland appears to bear more than twice the strain of good Roman.

CHAPTER VII.

MANUFACTURES OF IRON AND STEEL.

ON referring to chapter III. of this work, the reader will find ample information of the various steps from the finding of the iron ore in the mine; its removal to the surface; the smelting processes it has to undergo to convert it into pig-iron, and the subsequent treatment of this material to convert the iron into the malleable state, by the old method of refining, puddling, &c., and the invaluable invention of Sir H. Bessemer, by which the pig-iron is made its own refiner. The subsequent processes of converting iron into steel, have been described with full detail. Occasionally some of the manufactures of iron and steel have been in part described, or hinted at, but their importance demands a more extended treatment, and we purpose to devote the present chapter to the consideration of the various details which occur from the building of the largest iron or steel vessel to the making of a needle. We have already detailed the various processes of rolling, &c., by which malleable iron or steel are converted into bars, rails, and sheets. But numerous other forms of iron and steel are produced before the actual manufacture of iron and steel articles can be commenced. Repeating some already mentioned manufactured iron, includes the following:—Bars of various qualities, according to the object for which they are intended, and ranging in the trade from "common" to "B B B," and other branded qualities; angle and bulb iron, nail-rods, sheets called "singles," "doubles," "lattens," &c.: ship plates, boiler plates; light and heavy rails; puddled bars; fish plates, hoops, strips, rivet iron, horse shoe iron; sheet iron for galvanising; plates for tinning' to make tin-plates, besides many other forms that will be incidentally described as we proceed.

Now, all these articles just named may be termed the raw material of the shipbuilder, the boilermaker, and so on, through each grade of converting iron and steel into numerous useful forms. The range, as already mentioned, is very great, so much so, indeed, that no person unacquainted with the iron and steel trades, could form the slightest conception of its magnitude. But to facilitate the study in this chapter, we shall classify their manufactures, and so attempt to place before our readers as ample a description as lies in our power.

At page vii., and subsequent pages in the introductory portion of this work, we have given a brief account of the early history of iron mining, &c. But as the subject is of great interest and bears essentially on almost all the matters we shall have to deal with in this present chapter, we shall quote extracts from a paper read before a recent meeting of the Iron and Steel Institute at Liverpool, by J. A. Picton, Esq., F.S.A., on the "Progress of Iron and Steel Manufacture as Constructive Materials," for which we are indebted to the columns of *Engineering*. The author observes as follows:—

"Few of the material substances of which the solar system and the earth are composed are more widely diffused than iron. It has been discovered to exist in the solar atmosphere and in that of others of the heavenly bodies. As a mineral, it is found in various combinations over a large part of the crust of the earth. It gives its colour to the great Triassic and Devonian systems of rocks. In the living world it is equally diffusive. It imparts its lovely tint to the rose; the flush on the cheek of beauty is owing to its influence. 'The ruddy drops that warm the heart' derive their colour from the presence of iron.

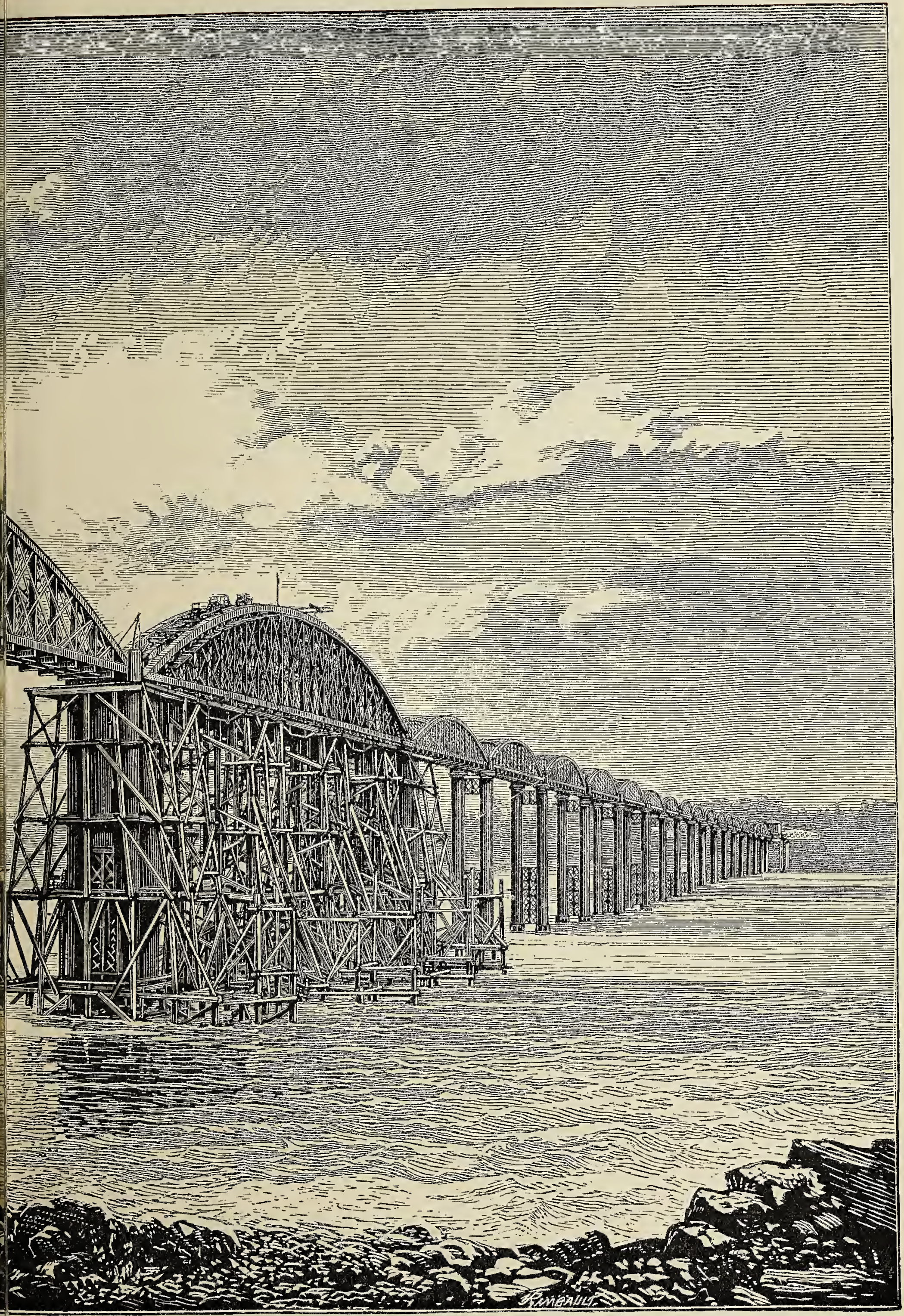
"Abundant as it is in nature, it was one of the latest metals brought into use. Flint and stone during countless ages constituted the implements and tools of mankind, succeeded in the heroic age by bronze, the manufacture of which was carried to a high degree of perfection and beauty.

"The earliest mention of iron is found in the Book of Genesis, chap. iv. 22, where we are told that Tubal-cain was "an instructor of every artificer in brass (or bronze) and iron.' The Hebrew word is ברזל, *barzel*, from a root signifying hardness and strength. We read also of the iron bedstead of Og, King of Bashan, and of Sisera's 900 chariots of iron, 1,300 years before our era.

In the time of Agamemnon iron was not in general use. No implements or weapons of this metal have been found in the remains of Mycenæ or of Troy. A large iron plate, however, has been discovered in one of the Egyptian pyramids. In the time of Homer iron was a rare and costly commodity, more highly prized than gold. The poet never mentions it as the material of armour or weapons, which were entirely of bronze, but in two passages in the 'Iliad,' iron axes are mentioned as valuable prizes in the athletic games.

"Iron was not employed for weapons by the Romans before the time of Hannibal in the second Punic war, but once adopted, the practical genius of the Roman people perceived its advantages, and entered upon its manufacture with avidity.

RAILWAY BR



OVER THE SEVERN

RAILWAY BRIDGE OVER THE SEVERN

"It is not probable that either the Greeks or Asiatics knew the process of extracting iron from the ore. Both iron and steel are found occasionally in a native condition, principally of meteoric origin. Hence it is supposed originated the Greek name for iron σίδηρος, from the same root as *sidus*, the Latin for the starry heavens.

"The Romans in Britain practised the art of extracting the metal from the ore on a large scale. Their works were principally carried on in what is now the Forest of Dean in Gloucestershire, and that of Anderida in Sussex, in both of which enormous quantities of scoriæ and cinders have been found. Their imperfect methods were unable to fuse the ore so as to produce cast iron, and it is probable that the metal was refined by several processes before it was finally adapted for use. The mines had been previously worked, for Cæsar on his arrival found the Britons in possession of iron, though it was employed more for ornament than use.

"This imperfect method continued down to the sixteenth century, when the introduction of the blast furnace led to the production of cast iron, the manufacture of which was for a long time principally fed from the scoriæ and cinder heaps left by the Romans.

"Once adopted, the superiority of iron over every other metal for tools and implements led to the supercession of all other materials for that purpose, and the use of iron entered upon a progressive career, which has extended with the advance of society in an ever-increasing ratio. One of the first purposes to which iron was applied was that of weapons and armour, the manufacture of which attained in the Middle Ages a very high degree of excellence; the hauberks of chain mail of the most intricate and delicate patterns, the chased and inlaid suits of armour, constantly changing its form, exercised the ingenuity of the armourers, and exhibit in the remains left to us a large amount of ingenuity and artistic skill. Offensive weapons were equally elaborated. The Toledo rapier and the Damascus scimitar had a world-wide reputation, and even in England the Sheffield whittle in the time of Chaucer had become famous for its quality. Iron work at this period was of the most elaborate description. The locks and keys, the hinges and bolts, the smith's work in grates and screens, exceed in beauty anything of the kind which has since been produced. Many specimens remain both in England and on the Continent, amongst which may be mentioned the ironwork in the church of St. Gudule at Brussels, the well-cover by Quentin Matsys at Antwerp, and, though of a much later date, the beautiful park gates at Hampton Court.

"The introduction of cast iron into general use in the seventeenth century effected a considerable change in the application of the metal. Its cheapness led to its extended use in the household economy of daily life; firegrates, stoves, pots and pans, gates, palisades, pipes, &c. This was no doubt in many respects a great advantage, but it had a very injurious effect on the art of the smith, superseding skill and ingenuity by the deadening process of routine in cast work, and substituting cheapness for excellence.

"From the seventeenth century onwards the use of iron in works of magnitude became much more general. Wrought iron having to be worked by hand, was necessarily limited in the size and weight of its productions, but cast iron was capable of applications of a more extended character. In 1755 Smeaton first used large pieces of cast iron for mill and engine work. From that period a leading part has been taken in this country in the development of constructions in iron. It has been well said that the triumphs of iron are principally due to Englishmen; they were the inventors of the steam-engine, the railway, the locomotive, iron ships, steamboats, the steam hammer, the telegraph wire, the cast and wrought-iron bridges, the ironclads, the monster guns, iron roofs, iron tunnels. One of the first employments of iron on a large scale was in the construction of bridges. In the sixteenth century a proposition was made by Italian engineers to construct a bridge in cast iron, but the scheme proved abortive. In 1755 an iron bridge was projected at Lyons, to consist of three arches of 82 feet span. Part of the work was actually prepared and put together in the builder's yard, but from some cause not recorded this attempt was also abandoned, and a timber bridge substituted. In 1777 the first bridge in England was designed by Mr. Thomas Pritchard, an architect of Shrewsbury, was constructed by Mr. Abraham Darby, of Coalbrook Dale, and erected over the Severn at Broseley in 1779. The span is 100 feet, the arch nearly semicircular.

"Soon after this date the idea of constructing bridges in wrought iron occurred to several French engineers, and several designs were prepared for works at Paris and elsewhere, but they were not carried out. In 1795 another cast-iron bridge was constructed over the Severn at Buildwas by Thomas Telford, 130 feet span.

"The boldest conception, however, was the cast-iron Bridge over the Wear, connecting Monkwearmouth with Sunderland, which was designed by the celebrated Thomas Paine, and was opened in 1796. It consists of a single arch 236 feet span, with a versed sine of thirty-four feet. For grandeur of idea, lightness of effect, and economy of material, it has never been surpassed. From that period to the present, the construction of iron bridges has proceeded in an ever-increasing ratio, until they have come, in works of magnitude, almost entirely to supersede stone. For some years cast-iron bridges had all the sway, constructed either with voussoirs or arch ribs, but have more recently been almost entirely abandoned for structures in wrought iron.

"Then followed the suspension bridge, of which probably the most graceful specimen is Telford's beautiful structure over the Menai Strait. This was originally designed in 1814 to span the River Mersey at Runcorn, on the site now occupied by the railway bridge; but the means were not forthcoming, and the pro-

ject slept until revived in 1819 for the new site, and was completed in 1825.

"The rapid development of the railway system, from its initiation by George Stephenson in 1830, has called out all the resources of the engineering mind, and led to bridges and viaducts of great boldness and skill. One of the most celebrated of these is the tubular bridge over the Menai, having two spans of 460 feet and two of 230 feet each. A vast amount of experiment, calculation, and research was expended on this design, which no doubt answers its purpose, but with an expenditure of material and an unsightliness of effect which seems to have deterred others from following in its wake.

"The lattice railway bridge over the Mersey at Runcorn, designed by the late Mr. Baker for the London and North-Western line, is a fine specimen of economy of material and efficiency in the result. Specimens of railway bridges abound on every side, and have developed the capabilities of iron to a wonderful extent. The two largest, probably, are the viaduct over the St. Lawrence, which consists of twenty-four spans of 242 feet each, and the more recent one over the Tay at Dundee (which was destroyed by a gale of wind in 1879, causing great loss of life, through the train passing over falling into the river). The latter was the most remarkable specimen of iron bridge building which has yet been constructed. It was two miles in length, consisting of 85 spans of various dimensions, eleven being 245 feet between the supports. The construction comprised plate, bowstring, and lattice girders in wrought iron, with cast iron columns and piers in combination with brickwork and masonry.

"The railway system has given an amazing impulse to iron construction, but it may be said with truth that it is itself the outcome of the development of iron. Consider for a moment what railways have done for the world. Sanguine expectations were entertained at their inception as to the future results, but it is almost needless to say that these expectations have been realised a hundred—nay, a thousandfold. What the formation of the grand old highways throughout Europe did for the Romans, the great road-makers of antiquity, the railway system has done for modern society, but in a far higher degree. It has changed the map of Europe, it has altered the boundaries of states, it has revolutionised the art and practice of war, it has given new directions to trade and commerce. Practically it has levelled the lofty summits of the Alps, and reduced the distance between the Atlantic and Pacific Oceans to a mere question of a few days. It has changed the centres of industry, opened up new sources of wealth and employment, created populous towns where existed only desolate wastes, brought the wild beauties of the lakes and mountains within reach of the toiling multitudes.

"It is not too much to say that in a very important sense we owe all this to iron and its development. Without iron these expectations would have been an idle dream; with it the results have become a sober reality.

"The motive power and initiative of these grand conceptions is the force of steam, harnessed down and pressed into the service of humanity by genius and skill. I have already said that without iron, steam power would have been an impossibility. The progress in each department has gone on *pari passu.* Every improvement in the manufacture of iron has given additional facilities to the steam engine, whilst steam power has given an impulse to the production of iron which has gone on increasing in more than a geometrical proportion. This will apply to all classes of machinery, of which iron may be considered the body, and steam the nervous energy which gives life and motion. The introduction of machinery on any scale of importance is of comparatively recent date, not reaching much further back than a century; yet now we see machinery entering into every manufacture, cheapening the prices of the necessaries, and administering to the comforts, of life. Of all this, iron is the basis and essential element.

"Let us now turn to another department, in which perhaps more gigantic strides have been made in the use of iron than in any other; I mean its application to naval affairs. The 'wooden walls' of Old England were formerly the nation's boast, the 'hearts of oak' of our tars was the sentiment of every nautical ditty. All this has passed away like a dream, and timber ships, with the exception of small craft for inland and coasting trade, are as obsolete as the canoes of our remote forefathers.

"One of the first to introduce iron into shipbuilding was Mr. Fairbairn, of Manchester, who in 1830 built three iron steam vessels for the Forth and Clyde Canal Company, and subsequently many others for use at home and abroad.

"The first sea-going iron ship was the Richard Cobden, built in 1844, at Liverpool, by James Hodgson and Co.; she was 136 feet in length, and 522 tons burden, builder's measurement. Some years elapsed before the example was followed to any extent, when by a sudden impulse, and with common consent, timber was abandoned, and iron became the order of the day. With the facilities afforded by iron enormous progress has been made in naval architecture. The Great Eastern steamship was built in 1858 on the Thames. Her dimensions are 679 feet 6 inches in length, 82 feet 8 inches beam, and 48 feet in depth, fitted (at first) with screw engines of 1,600 horse power, and paddle engines of 1,000. Probably she was in advance of her time, the skill in her arrangements not being equal to the grandeur of the conception, but the tendency of late years has been to increase the dimensions, particularly in length.

"The application of iron to ships of war has probably exceeded the progress in any other department, if we consider the enormous masses of iron employed, and the crucial experiments to which they are subjected. A modern turreted ironclad, with her 20 inch or 30 inch coating of solid metal, her engines of many thousand horse power, her almost automatic machinery for performing every naval operation, her capacity for

Sir Isambard Brunel

destruction in the immense armament she carries, presents a representation of the state of modern society, both in its scientific and social aspects, perhaps as striking and illustrative as can be anywhere found.

"Closely connected with this is the application of iron to the purposes of war, whether by land or sea. Within the last few years the contest between the aggressive power of ordnance on the one hand, and the defensive power of iron plating on the other, has been carried to an almost inconceivable extent. The calibre of the gun is increased to pierce the plating, and the thickness of the plating is increased to resist the impact, so that we have arrived at guns of 100 tons and upwards, with projectiles of over 1,500 pounds weight, resisted by armour plates twenty inches or thirty inches thick. At what point the contest is to end no man can foresee. Iron, also, is being largely utilised for defensive purposes by land.

"When we look at the ironclads, the rams, the torpedoes, the turrets, the large guns by sea, and the plated forts, the railways, telegraphs, and other appurtenances by land, we see that iron plays an important, perhaps the most important, part in modern warfare.

"But whilst iron has thus so largely been employed for the purposes of destruction and defence, on the other hand it has given facilities for mutual intercourse and peaceful co-operation never before known. The railways I have already mentioned; but we must not forget the telegraph wires which encompass our globe, and form, so to speak, the nervous system of the world. It is iron, and the modern facilities for its manipulation, which enable us so to bridge over space and annihilate time.

"The subject is so vast, that I might go on enumerating to an almost boundless extent the various uses and applications of iron, which are constantly increasing in their adaptation to every purpose of human society, but time will not permit. I will only notice the progress of iron in another department, that of building construction. The old materials for building were stone, brick, and timber, and with these, especially the first, some of the noblest monuments of art and skill have been constructed. Iron, in ancient times, played a very subordinate part in building. It is only in modern structures that its advantages have been appreciated. At first cast iron was employed for columns and struts supporting weight, and subsequently for girders and beams, but the treacherous nature of the material when subjected to cross strain rendered its use very hazardous. By degrees wrought iron, by means of improved machinery for rolling, was rendered adaptable for building purposes. A great impulse was given to its employment by the construction of the Crystal Palace in Hyde Park in 1851, in which, for almost the first time, the design was adapted to the nature of the new material. This led the way to further improvements. Rolling mills were constructed to manufacture girders and joists of lengths and sections not previously attempted, and the result has been the employment of wrought iron to a very large extent in roofs and floors. Concurrently with this progressive movement, the demand for roofs of very large span in railway stations has stimulated design, and led to the construction of iron roofs of a magnitude never before contemplated; the width of span in several cases approaching 300 feet, and the total areas covered, as in the stations of St. Pancras, that at Birmingham, and at Lime-street, Liverpool, are such as cast into the shade all former constructions of a like kind.

"Iron floors have not in England been adopted to any very large extent, but in France, especially in the new quarters of Paris, they are almost universal. The girders and joists are of rolled iron, with iron laths dropped in between, on which is spread a coating of concrete, rendering the structure perfectly fireproof.

"Iron lends itself readily to the construction of dome roofs, of which recent specimens are found in the reading-room of the British Museum, and in the one erected in connection with the Free Public Library, Liverpool.

Notwithstanding the enormous development of railways both at home and abroad, and the depression consequent on excessive and imprudent expenditure, there can be no doubt that the railway system has still a great future in store. There yet remains much land to be possessed. European enterprise will never cease until all the lines of intercourse where commerce finds its way are provided with railways.

"The adoption of steel for rails, thanks to the genius and enterprise of Sir H. Bessemer, Dr. Siemens, and others, has much facilitated these operations, and holds out to the British manufacturers the prospect of a profitable employment of their capital.

"Machinery, whether locomotive or manufacturing, is undergoing a constant but quiet revolution, consisting in improved economy of materials, rapidity of motion, and increased efficiency. Iron ships, especially steamships, are increasing in size and power, to which the introduction of steel plates will impart greatly increased advantages. In warlike affairs, whether the contest between armour-plating and armour-piercing has reached its acme, I will not take upon myself to say. The final decision of the problem is one of great interest as to the future employment of iron for such purposes.

"The facilities of iron, especially wrought iron, for all engineering constructions are more and more appreciated year by year; but with some few exceptions there is a great defect runs through them all in the absence of anything of æsthetic taste in the designs. The ancient motto for building was 'Strength, commodity, beauty.' The two first have been attended to almost to the entire neglect of the third. This I cannot help thinking is a great mistake. The grand engineering works with which the surface of our country is studded should have a dignified and noble aspect. They should minister to the sense of beauty and fitness as well as to that of strength and power; but too frequently the reverse is the case. I will refer to an instance

or two. The railway viaducts built by Brunel over the rivers at Chepstow and Saltash are grand specimens of constructive skill, but their aspect is repulsive in the extreme. Let any one compare London Bridge, with the graceful curves of its arches and its simple yet elegant design, with the iron bridge of Blackfriars, or still worse, with the railway bridges crossing the Thames; the contrast will be found painful in the extreme.

"The railway bridge at Runcorn by Mr. Baker, with its light iron lattice work and the sweeping lines of the viaducts on each side, is a fine and noble structure. Telford's suspension bridges at Conway and the Menai are charming in their outline and fairylike in their construction, whilst their neighbours the tubular bridges are the very incarnation of ugliness. This is a defect not inherent in the material, for iron readily lends itself to any shape of beauty. It rather arises from contempt or inadvertence, looking at strength and power as the only elements required. Let us hope that a better spirit may be evoked, and that our future engineering works in iron may be as distinguished for beauty of design as they are now renowned for grandeur and efficiency.

"In architecture properly so called, iron is doubtless destined to play a very important part. Hitherto architects as a body have neglected iron. When employed, they have striven to hide it from sight, and seem to apologise to themselves and the world for being obliged to use it instead of brick or stone. Its use, however, is being forced upon us, and on every side we are met with iron sheds, iron churches, iron houses. The designs of these are usually hideous to behold, but why should this be so? Why should architects not face the difficulty, and instead of letting iron master them, convert it into their handmaid and servant? The mediævalists followed a different course. They took the material which lay before them, and by a happy audacity in design and construction, they produced effects which for composition of masses, picturesqueness of outline, and brilliance of inventiveness have ever since been the admiration of the world.

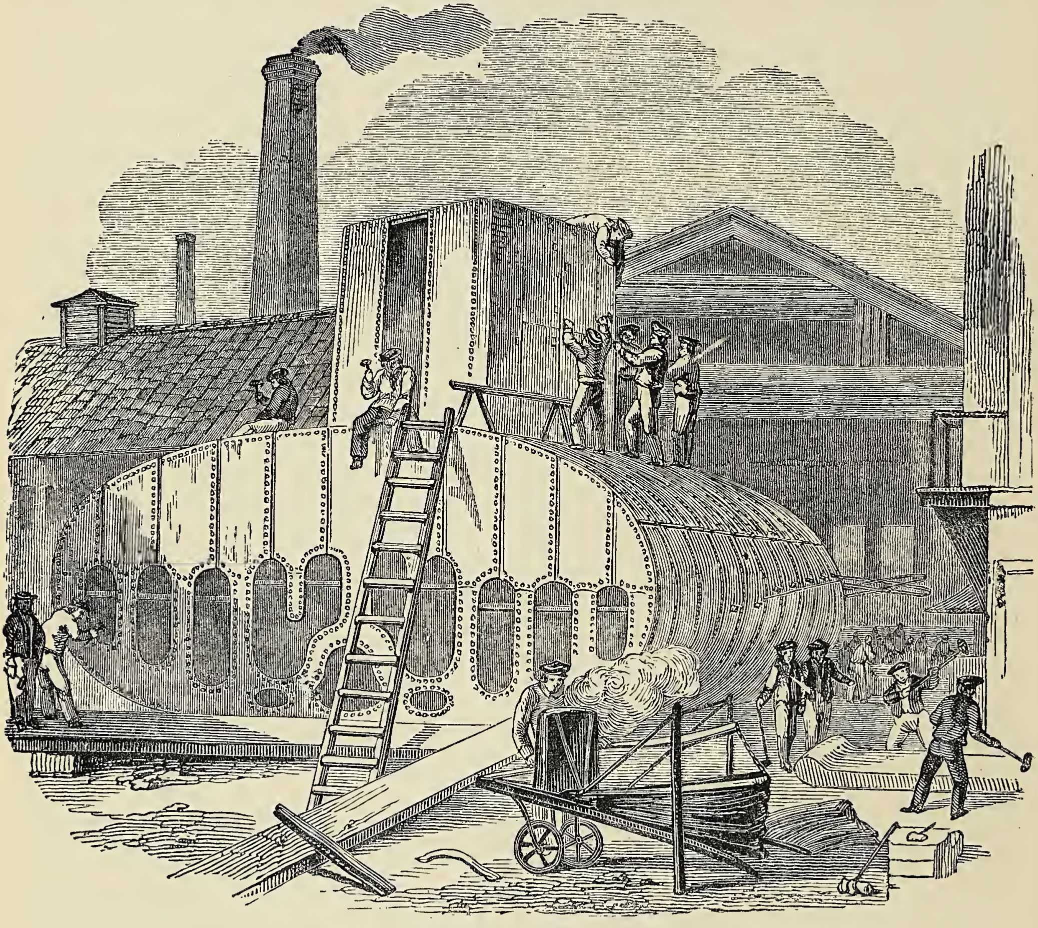


Fig. 162.—Old-fashioned Flue Steam-Boiler.

"Looking to the future, there can be no doubt that iron is every day becoming a more important factor in the world's affairs. The ages of stone and bronze, the times of darkness and ignorance, have passed away, and with the use of iron came in power, and knowledge, and light. It is destined to work yet greater wonders. It is its mission, sent by a gracious Providence, to lighten man's labours, to given him the mastery over Nature, to enable him to explore her secrets, to comprehend her laws and to turn them to the best advantage for the welfare of humanity. The ages of gold and silver may serve for the theme of the poet's fancy or the dream of the enthusiast, but the age of knowledge, and progress, and power, and wisdom is the of age iron."

The foregoing *resumè* of the progress of iron manufacture, especially during the last century, cannot be read without deep interest, as it describes a development of human intellect, skill, and power unequalled in any other branch of industry. But although an immense quantity of iron is used in modern days, it must be borne in mind that this is done economically. In the paper just quoted, reference has been made to the point, and instances have been given in which an equal amount of strength has been obtained, together with beauty, or, at all events, elegance in appearance, as would have resulted from the employment of much greater weight of the raw material.

But not only has economy of material been considered, but also economy of space. This is especially instanced in the case of the modern locomotive engine in which an amount of power equal to 1,000 horses can be developed in an exceedingly small space, both for boiler and engine. In steam boilers this is especially remarkable. Some forty years ago, speaking from personal remembrance, the boilers of all the steam-boats, running between London and Margate, Ramsgate and Dover, were of the old-fashioned flue style. The flues inside the boiler were large enough for the young sweep to walk through upright to clean out the soot at the end of each voyage. The flues of course being really cubical boxes, or squares, could not bear more than a very moderate pressure, say from five to

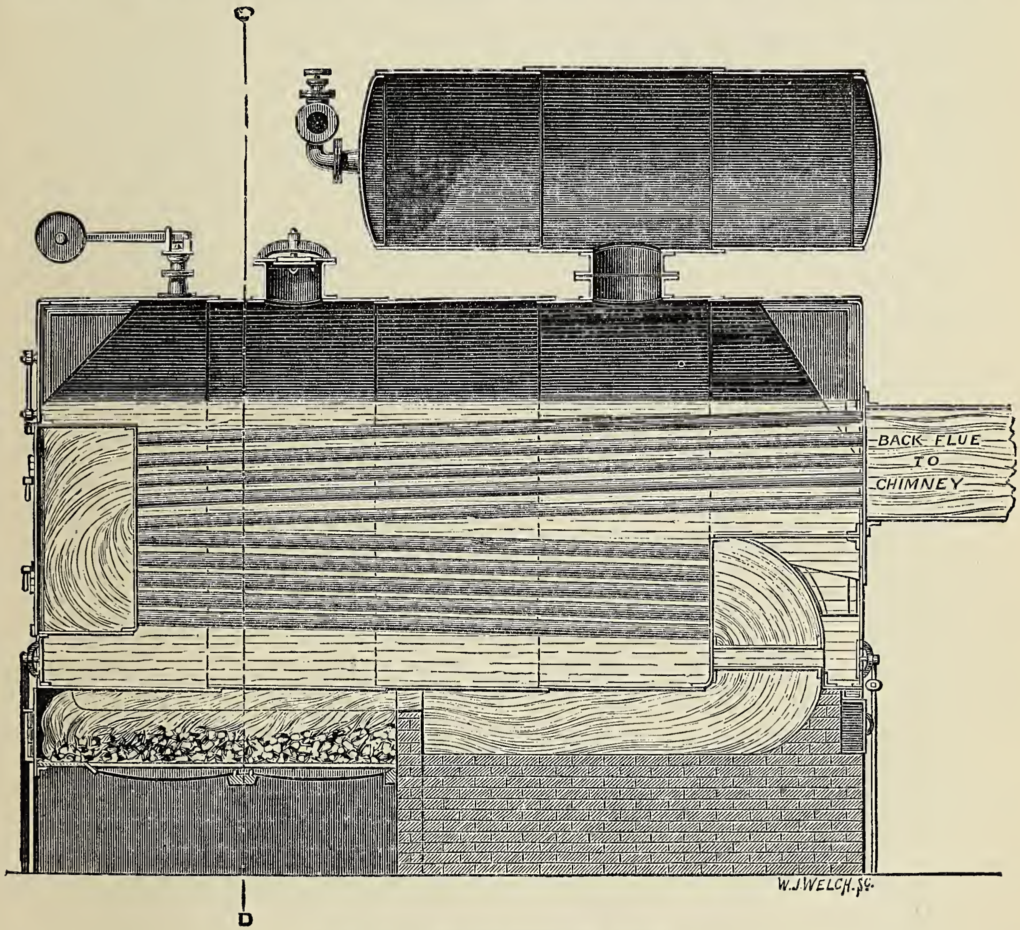


Fig. 163.—Patent Multitubular Boiler.

fifteen pounds per square inch. The cylinders were of enormous size, and the boilers and engines took up so much space, and were so heavy, as greatly to impede the vessel's progress, even of ten miles an hour, while now with the tubular boiler, and improved engines working at a pressure, safely, of say 100 pounds per square inch, a speed of fifteen miles an hour is attained by vessels of some thousand tons and upwards, while steam launches are constructed that will run at the rate of twenty-five miles per hour.

Fig. 162 represents one of these old-fashioned boilers with the flues just described.

By way of contrast we may refer to one of the the folio illustrations of this work in which a four-wheeled tank engine, constructed by Messrs. Appleby of London is represented. The tubes inside the boiler will be easily traced, and illustrate those in general use in modern locomotives. In Fig. 163 is an illustration of Appleby's patent multitubular boiler, that still further shows the improvements that have been effected in regard to space, weight, power, &c. In a careful set of experiments made by Mr. T. Box on a 40 horse-power boiler of this type, Messrs. Appleby state that it was found that one pound of Welsh coal evaporated 11·8 lbs. of water; one pound of Newcastle coal 10 lbs., and that inferior coal evaporated 8·4 times its weight of water. Here is an enormous economy in the consumption of fuel, for we have known the old-fashioned flue boiler consume from 15 to 20 lbs. of coal per horse power per hour, doing inefficiently the same kind of work which the modern boiler would perform for two or three pounds per horse power.

In the plethora of objects which the vast range of iron and steel manufacture presents, it is difficult to know where to commence. Perhaps the best course will be to deal with constructions of the largest size, and thence gradually descend to articles of less magnitude, but, which, in their place, are absolute requisites of our daily life.

Wood, Iron, and Steel Ship-building.

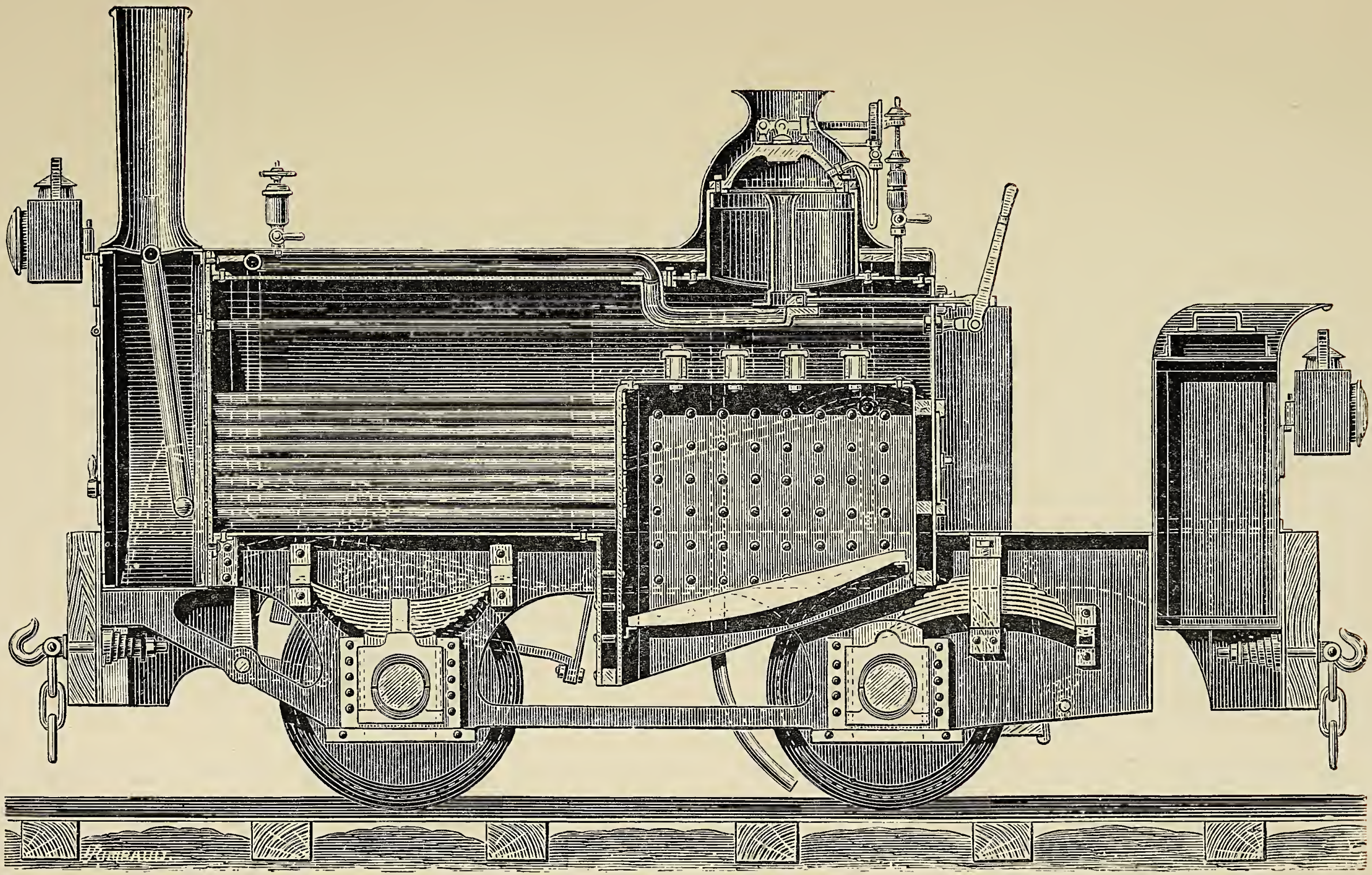
It will be desirable, before entering on a description of modern ship-building in iron and steel, to trace as briefly as possible, the various steps that have been marked in the progress of the art of travelling by water to the days of the iron and steel age.

It is a very probable conjecture that the first form of boat or vessel in most countries was the *raft;* a collection of trees or logs rudely fastened together with ropes, formed most probably from the bark of the very trees which constituted the raft, or from some other coarse material. Experience would soon teach the navigators that they were deficient in the power of directing such a fabric so as to be certain of reaching their place of destination in spite of winds and currents. To remedy this defect a simple addition was contrived, consisting of a few thick planks of wood thrust down into the water to the depth of three or four feet between the logs which formed the raft; these, being raised or lowered according to circumstances, were found to aid a man considerably in the management of his vessel. That such was the precursor of the boat or ship is rendered probable by the usages of rude nations in our own day; the less ingenious of whom construct vessels which approach much more nearly to the form of rafts than of boats.

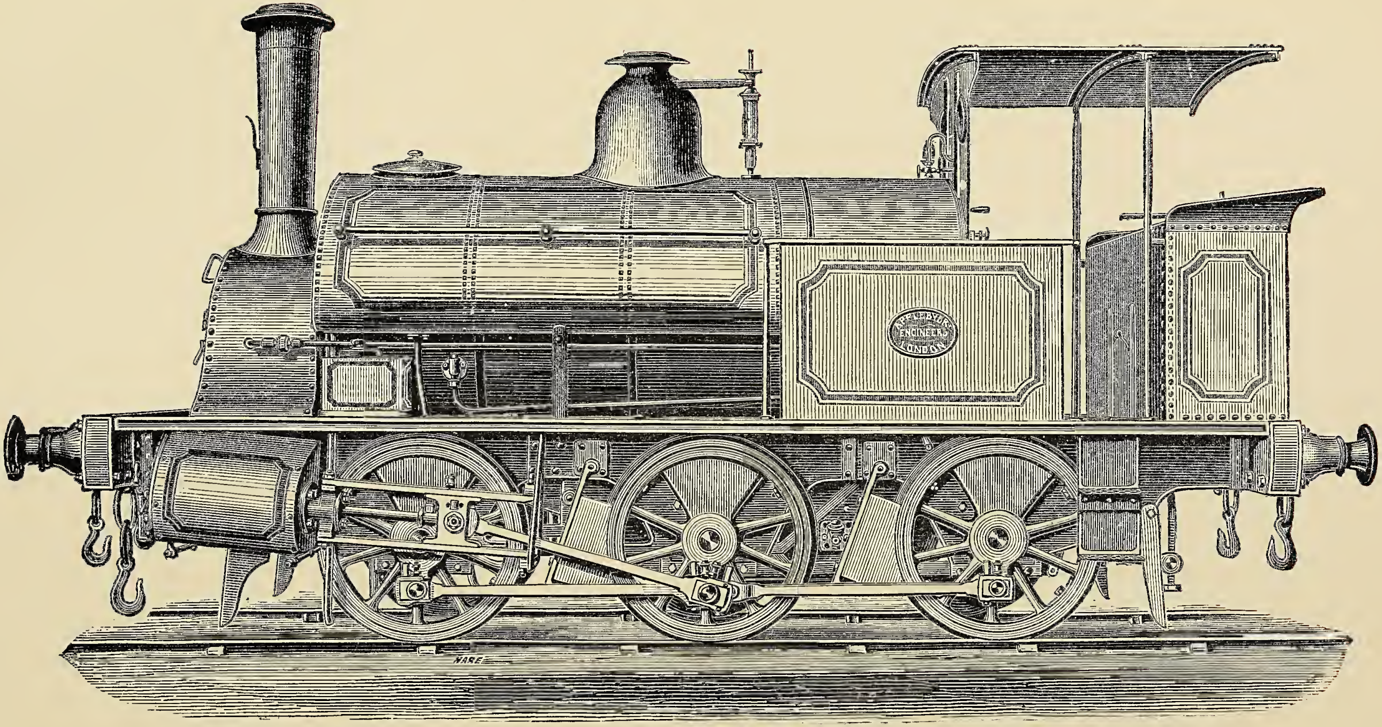
Charnock traces with much minuteness the steps whereby commerce on the one hand, and war on the other, led to improvements in the arts bearing upon ship-building. The Phœnicians, who were among the most enterprising of commercial nations in early times, were also among those who attended most to the improvement of ships; to which, indeed, they owed no small share of their importance. The wars between the Greeks and other nations, separated one from the other by the open sea, naturally led to the improvement of vessels in another way, so as to produce the "war-galleys" of classical times, on which so much has been written, and the true character of which is at the present day so little understood. The Greeks had vessels built for a particular kind of merchandize, or for a particular part of the sea, each one having certain peculiarities as to form or size. In the construction of these merchant vessels, the plane, cypress, oak, fir, and cedar trees were employed.

In building the war-galleys, where stout and strong timber was an essential requisite, a curious idea prevailed as to the proper time for cutting down the oak or fir trees employed. There was a notion that it would be improper to cut down any timber for the purpose of ship-building except on the seventeenth day of the moon; because the moon being then on the wane, the sap or internal moisture, which is the grand cause of early decay, would be sunk or considerably lessened. It was afterwards laid down as a rule, by those who thought they had discovered some connexion between the age of the moon and the state of trees, that the time of cutting might be on any day between the fifteenth and the twenty-third day of the moon's age: but that if these limits were transgressed, the wood so cut down, and afterwards used for ship-building, would decay and become worm-eaten in a very short space of time. Even the direction in which the wind blew was taken into account, and this had its particular rules at different seasons of the year: for example, in the beginning of autumn it was not considered prudent to cut down trees for this purpose unless the wind was westerly, or, in the winter, unless it blew from the north.

The kinds of wood employed in building the war-galleys were chestnut, cypress-wood, pine, elm, oak and fir. The hull of every ship and galley consisted of a prow or head, a poop or stern, and body or mid-ship frame. In the early form of vessels, intended chiefly for commercial navigation, there was no keel; they were flat-prowed, round, drawing little water, and of very great breadth in proportion to their length, so as to be able to contain a larger amount of commodities than would be the case under the adoption of any other form. The floor-timbers



FOUR-WHEELED TANK LOCOMOTIVE—LONGITUDINAL SECTION.



SIX-WHEELED TANK LOCOMOTIVE.

were contiguous, and there appears to have been some means known, by steaming or otherwise, of bending timber so as to make it conform to the shape of the vessel. But it became apparent by degrees that it would be more available to build up a ship piece by piece; by having a keel or central spine running from end to end, and making a framework by attaching side ribs to this keel. The separate timbers of this framework rose at right angles from the keel, and planking was put on the outside of them, in layer after layer parallel to the keel; the planks being fastened to the ribs by bolts or pins. There was a deck thrown across the vessel, at a height from the keel greater or less according to the size of the hull; and at different parts of the side, between the deck and the water-level, were holes at which the oars were thrust out for rowing the vessel.

As a means of preventing water from finding entrance between the planking, a stuffing or caulking was rendered necessary. The first application for this purpose among the Greeks is said to have been nothing more than the use of sea-shells, which were reduced to powder, mixed up with water into the state of a paste, and introduced into the chinks; being liable, however, to crack, by the yielding of the vessel, this composition fell out by degrees, and soon failed to answer its purpose. The next step was to burn the lime, as a means of making the mortar more adhesive; and afterwards wax and pitch were employed. A far better plan, and one nearly in conformity with modern practice, was found to consist in the use of the coarse outer fibres of the flax-plant, bruised and divided by being beaten with a mallet, and driven in between the planks of the ship. The bottom of the vessel was also in some cases coated with a layer of melted wax or pitch. In others, as is stated by Maurice, the ship-builders "were accustomed to use hides, properly prepared and hardened for the purpose, which, being stretched and firmly attached to the bottom, served as a species of sheathing, and being well payed or covered with a sufficient coat of resin or pitch, proved a very considerable protection to it against those injuries which would have arisen from the salt water being in constant contact with it."

A curious proof has been brought to light of the existence of the modern practice of "caulking" and "sheathing" ships in early times. Trajan's galley was dug up from the Lake Riccio in Italy, after having lain there 1,300 years; and, on being examined, the seams were found to have been caulked with linen, and the exterior of the vessel coated with Greek pitch, over which was an external sheathing of lead, rolled or beaten to a proper degree of thinness, and closely attached to the planking by small copper nails.

As the commercial vessels of Greece and Rome were chosen rather for capacity and safety than for other qualities, they were formed to pass through the water less rapidly than the war-vessels. Indeed, the war-galleys, using oars only, are said to have surpassed in speed the merchant-galleys even with all their sails employed; and this difference was still more marked when the war-galleys used sails as well as oars. The rostrum, or sharp beak of these galleys, was one of the most formidable weapons of offence in naval warfare; and one of the objects in the mode of navigating, whether by oars or sails, or both, was to impel this beak with immense force against the enemy's galley. By lengthening the beak considerably, the speed of the vessel was increased, and the momentum became greater; but the beak itself was at the same time weakened by the lengthening, so that the problem to be solved was—how to obtain the greatest speed and impulsive force with the greatest strength of beak. The beak was made of the toughest wood, such as elm, ash, or oak. The mode of attack was either to sheer up suddenly so close alongside the enemy that the stroke of the beak might shatter the oars on the side attacked, and by that means render the vessel in great measure unmanageable; or, by striking the enemy with the greatest possible force near the midship, cause the beak to penetrate the side of the opposing vessel, or to overset it in case it was fortunate enough to resist the first onset. Sometimes the enemy attempted to steer round the stern, and to demolish the rudder. To some extent the vessels resembled the modern warships with rams beneath the water.

The decorations of the stern, or poop, differed very materially from those of the head, and were more magnificent. It was customary, also, to fix at the extremity of it an upright staff or pole, to which were affixed streamers of various colours. It was, moreover, usual among many nations to add some carved ornament, frequently gilt. The sails were often striped with various colours; and more particularly on board the galley belonging to the commander of the fleet, were entirely purple. Flame-coloured sails were also in use; and so fanciful was the taste in respect to this part of a ship's fittings, that sails were sometimes woven of threads previously dyed of different colours, so as to produce that diversity of appearance know as "shot" in reference to silk. In the time of Trajan ideas of luxury were carried so far in respect to these matters, that the name of the emperor was embroidered with gold or silver on the sails of the war-galleys.

The best modes we have of obtaining any notion of the form of ancient vessels are from the paintings and *bassi-relievi* at Pompeii, Thebes, and similar places; for however uncouth these representatives may appear, they were undoubtedly intended by the artist to convey a correct idea of the vessels. In Figs. 164 and 165, are sketches of Greek and Roman vessels, derived either from Pompeii or from the Townley Gallery at the British Museum; in Fig. 166 we have an odd representation of a shipwright, from an illuminated manuscript; in Fig. 167, a Roman galley, taken from a similar source.

It would be very interesting to enter on a description, and to illustrate the various contrivances made for travelling by water in different parts of the world in ancient and modern times. But this our space will not permit of. We must, for the same reasons, omit noticing the first contrivances which were adopted by the early

inhabitants of our country, and resume the narrative of our historical sketch, at about the fifteenth century.

From the time of the Crusades to the reign of Henry VIII., the naval proceedings of England were chiefly comprised in the conveyance of troops to and fro between England and France; in maintaining actions against the French and Spanish fleets at different times; and in keeping up a coast communication between the different parts of the kingdom. Foreign commerce was much more in the hands of the Genoese, the Venetians, and the Hanse Towns, than in those of England, and our commercial navy was, in consequence, of limited importance. In the reign of Henry VII., however, a new order of things arose. "The invention and use of gunpowder, at least in Europe, was then of no very ancient date: its introduction into ships was still more recent; and the contrivance of port-holes, the honour of which is attributed to Descharges, a French ship-builder at Brest in the reign of Louis XI., did not take place till nearly fifteen years after Henry had ascended the throne. These separate and progressive additions to, or improvements on, the equipment of a ship intended for warlike purposes, rendered very material alteration in its structure, and an enlargement of its dimensions indispensably necessary. Previous to the commencement of this new system, no distinguishing line of separation existed between those few vessels which had been specially built for the king's service, and such as were used for mercantile purposes, except only that some of the former were of superior dimensions. The case now became altered; and though on occasions of particular emergency, it was still found necessary to add, as a reinforcement to the navy, a number of the largest vessels that could be hired, not only from the English merchants, but from the Genoese, the Venetians, and the Hanse Towns, the king's ships began to form a distinct and secluded class, and to be kept solely for the service and use they were constructed to answer."—(Charnock.)

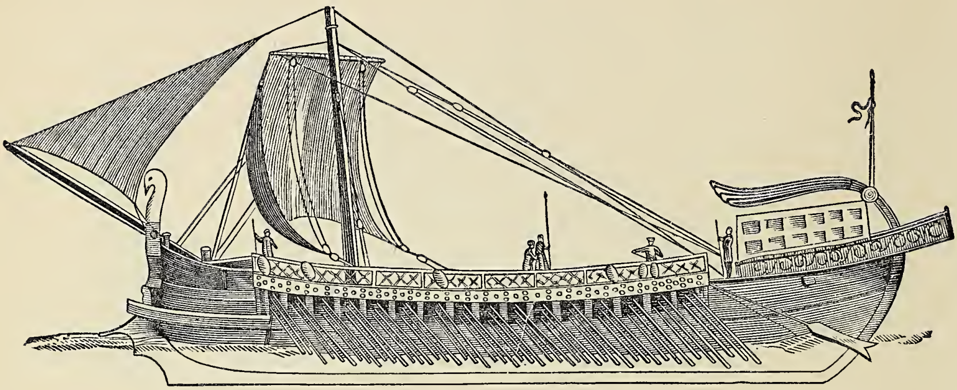


Fig. 164.—Ancient Ship. (From a Painting at Pompeii.)

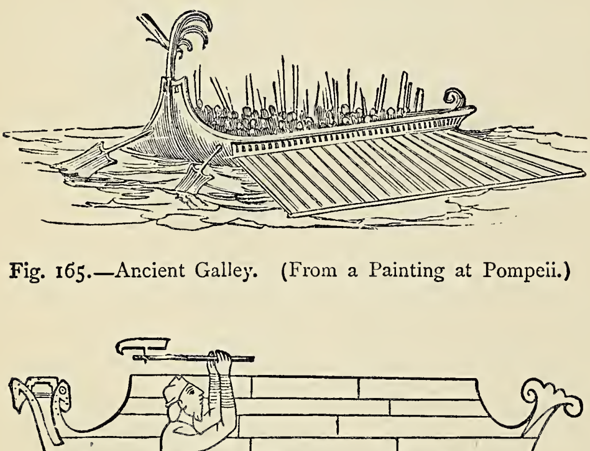


Fig. 165.—Ancient Galley. (From a Painting at Pompeii.)

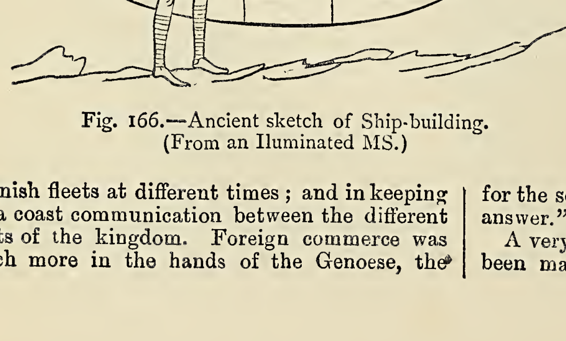


Fig. 166.—Ancient sketch of Ship-building. (From an Iluminated MS.)

A very remarkable advance indeed must have been made from the feudal times before the

"Henri Grace-à-Dieu" could have been built. Its construction arose out of a contest between the English and French in the Channel. The "Regent," the largest vessel that had up to that time ever been built in England, encountered the "Cordelier," a French ship, having 1,600 men on board; and both were clumsy and ill-constructed vessels, very difficult to manage.

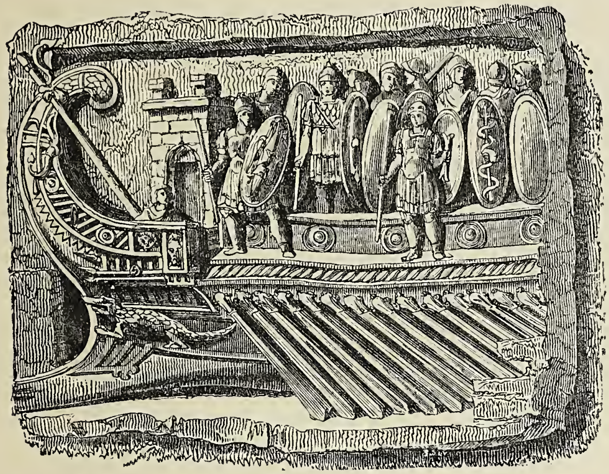


Fig. 167.—Roman Galley. (From a bas-relief.)

After engaging for about an hour, the French admiral set his own ship on fire, and the flames communicating to the English ship, both were destroyed. Henry thereupon ordered a new ship to be built, larger even than the "Regent;" and the "Henri Grace-à-Dieu," was constructed. This immense ship (Fig. 168), was rated at 1,000 tons, and had 122 guns of various sorts, though only thirty-four of these were such as would now be included in the mention of a ship's power, the rest being very small. There is a picture at Windsor Castle, and a copy of it at Greenwich Hospital, both of which are supposed to represent this "Great Harry;" the original picture being (as is also supposed) by Holbein. From these representations the ship appears to have been much more bulky and showy than sea-worthy. The king is represented standing on the main deck, with attendants near him; the sails and pendants are of cloth of gold; the royal standard is flying on the four corners of the forecastle, and also on the ship's stern; and the arms of England and France are depicted on the front of the forecastle, and also on the ship's stern. The vessel stood too far out of the water to be safe;

Fig. 168.—The "Henri Grace-à-Dieu," built by Henry VIII.

and it was but little used. After passing almost a useless existence for more than forty years, this vessel (built in 1509) was accidentally burned at Woolwich in 1553.

One of the great circumstances which led to the increase of ship-building was the spirit of adventure which sprung up about the reigns of Henry, Edward VI., and Elizabeth. The discovery of America had so excited the cupidity of Europeans of all ranks, that expeditions were sent out one after another, either to colonize new countries already discovered or to discover others. These were sent out in some cases by the government, but in most instances by private persons, either in companies or individually. "The spirit of commerce," says Sir James Mackintosh, "mingled with a passion for discovery, which was exalted by the grandeur of vast and unknown objects. A maritime chivalry arose, which equipped crusades for the settlement and conquest of the New World. Great noblemen, who would have recoiled with disgust from the small gains of honest industry, eagerly plunged into associations which held out wealth and empire in the train of splendid victory. . . . . For nearly a century it became a prevalent passion among men of all ranks, including the highest, to become members of associations framed for the purpose of discovery, colonization, and aggrandizement, which formed a species of subordinate republics, the vassals of the Crown of England."

It speaks much for the rapidity of the commercial progress, that the fleet which was sent out under Sir Francis Drake in 1587, to attack the "Armada" in the harbours of Spain, was composed of ships furnished by the merchants of London—not wholly out of a feeling of patriotism, however, for they hoped to pay themselves the outlay by the plunder of the enemy's ships.

The force which the Spaniards were able to bring against England in 1588, under the proud title of the "Invincible Armada," was of such extent as to show that naval tactics had made a tolerably rapid progress. It consisted of 130 vessels; of which sixty-five were galleons and large ships, twenty-five were "pink-built" ships, nineteen were tenders, thirteen small frigates, four galeasses, and four galleys. These vessels contained about 20,000 soldiers, 8,000 mariners, 1,200 rowers in the galeasses, and 800 in the galleys, 2,000 volunteers, and about 2,500 pieces of artillery. To oppose this enormous force Elizabeth had at first only about thirty vessels of moderate size, but these were increased to 180 of various kinds before the contest actually began. What was the disastrous fate of this much-vaunted "Armada" every reader of history knows.

Fuller, speaking of the navy in his time, says:—"Our ships, so active to turn and winde at pleasure, must needs be more useful than the Spanish galleys, whose unwieldiness fixed them almost in one posture, and maketh them the steadiest markes for their enemies. As for Flemish bottoms, though they are finer built, yet as the slender barbe is not so fit to charge with, they are found not so useful in fight. . . . . I am credibly informed that that mystery of shipwrights for some descents hath been preserved successively in families, of whom the Pets about Chatham are of singular regard. Good success have they with their skill, and carefully keep so precious a pearl, lest otherwise among so many friends some foes attain unto it." He lays down as a political axiom that "it is no monopoly which concealeth that from common enemies the concealing whereof is for the common good;" and he concludes with the wish, "may this mystery of shipmaking in England never be lost till this floating world be arrived at its own haven, the end and dissolution thereof." In the reign of Charles I. considerable advance was made in the art of ship-building. The "Sovereign of the Seas," by far the finest vessel that had up to that time been built in England, was laid down in 1635, and, after existing for fifty years, it was burnt at Chatham. At first it was a lofty and magnificent ship (Fig. 169), the expense of which was one cause of the troubles between Charles and his parliament; but upon being cut down a deck lower, it proved a very formidable ship of war.

We must next describe the method of construction of wooden vessels of modern times, which, of course, formed the pattern or model on which our iron vessels were begun.

The place in which all vessels are constructed is called a ship-yard, the size of which varies from a few square yards to an area of acres, according to the extent of business carried on, whether in wood or iron ship-building. Fig. 170 represents a wood ship-building yard. In it appear vessels in course of construction or completion, with raw and cut timber, and other materials.

One of the chief buildings in a ship-yard where the operations are carried on is the "mould-loft." This is a room, the length of which rather more than equals half the length of the largest ship to be planned there; and on the boarded floor of this loft innumerable lines are chalked, to mark the several parts of the vessel. The architect, in the first place, draws out his plan upon paper, on a scale of a quarter of an inch to the foot; and from this plan he marks the lines on the mould-loft floor the full size of the intended ship. This chalked plan comprises a horizontal plan of half the ship in the direction of its length, and a transverse section of the ship at its greatest breadth. From these as a standard the architect proceeds to chalk numerous other lines, representing the timber ribs or frames which form the hull of the vessel. Thin pieces of plank are taken, about three-quarters of an inch in thickness, and cut into forms corresponding with the lines on the floor. These shaped pieces, which constitute collectively the "mould" of the ship, are intended solely to guide the shipwrights in cutting their various timbers to form the hull of the vessel. The concave and convex edges of the mould-pieces, and certain chalk-marks upon their surfaces, give the length, breadth, depth, and peculiar form of all the ship's timbers. So numerous are the various timbers required for a large ship,

that in planning an East Indiaman more than 100 of these moulding-pieces are prepared.

If we look at Figs. 171, 172, 173, 174 and 175, we shall see how varied are the forms of these timbers, intersecting each other at almost every imaginable angle. The main timbers which form the ribs, or framework of the hull, are, in particular, remarkable for their curvatures—since it is by these curvatures that the general shape of the vessel is determined. The builder of the vessel arranges, in the first instance, what shall be the "tonnage" of the vessel, or the general capacity of the hull, and the relation between the length, breadth, and depth; and the ship-architect then determines how to attain this object in practice. It is his office, also, to attend to all improvements which may be made in the effect of the vessel's form upon the speed attained, and to devise the means for working them out practically. The result of all his labours, however complex they may be, is shown in the set "mould-boards" which he prepares, and which form the connecting link between the naval architect and the shipwright.

When the "mould" is prepared, the pieces of which it consists are handed over to the master-shipwright to assist in building the vessel; and thence commence the busy operations of the ship-yard generally. The "converter" is one of the first persons employed in this important train of operations: his duty consists in selecting the logs of timber fitted for each particular purpose, and superintending the shaping of them. The oak and elm trunks which form the principal materials for the framework of a ship are very varied in size and shape, and considerable judgment is necessary in selecting them; for the direction of the grain is an important element in the strength of a piece of timber. Suppose, for illustration, that a beam with a peculiar curvature was required: if a "knotted and gnarled oak" could be found, whose crookedness of trunk bore some resemblance to the curvature of the intended timber, it would not only be a saving of material to use this trunk for such a purpose in preference to another, but the beam so produced would be actually stronger, since the direction of the grain would conform pretty nearly with the curved form of the timber. Such is the kind of skill in selection which the "converter" has to show; and he must also possess an intimate knowledge of the quality of timber, not only from its appearance when cut, but from its exterior, as a means of determining the fitness of every particular piece for the purpose to which it is to be applied.

When the proper logs are selected they are placed across a saw-pit in the usual way, and cut by saws worked vertically by two men. The "mould-boards" are applied to the logs one by one, and the cuttings of the saw are made in conformity with them. Instead of cutting rectangularly, as in the common saw-pits, the logs are placed at various angles, so as to be cut into the seemingly-strange shapes which so many of the timbers of a ship present; and the directions of the cuts vary so remarkably and so frequently, that it is found impracticable to apply machinery to the cutting of the timbers.

The sawing, or "converting," is carried on under sheds; and the pieces, as they are cut, are carried to the "building-slip," or place where the ship is to be constructed. This is generally an oblong space declining gently towards the sea, a river, or a basin, in such a manner that the ship, when finished, may slide down into the water at high tide sternwise. The ground is cleared and made smooth, and a row of blocks is laid down, each block being transverse to the length of the ship, and the whole being sufficient in number to extend from end to end of the slip; they are made of oak, and are piled one on another to the height of three or four feet. The upper surfaces of all the blocks are in a straight line, slightly declining towards the water.

These blocks form the support on which the whole of the ship is built, beginning with the keel. This important part of a vessel's frame or body, forming, in fact, the back-bone of the whole structure, is made of elm; and, as no elm-tree is long enough to make it, except for small vessels, two or three trunks are joined or "scarfed" together to produce the required length. It may well be supposed that great strength must be exhibited in the mode of scarfing, to enable the keel to bear the enormous strain to which it will afterwards be subjected. The keel is grooved and cut in various ways, for the reception of other timbers, both at the sides and the ends.

As the keel is the main support of the bottom, so are the "stem" and the "sternpost" the main supports of the two ends. The stem is a large timber which rises in a curved form from one end of the keel, and the sternpost is another that rises nearly perpendicular from the other end; both are formed of oak, and both are attached to the keel with great strength. Adjacent to and contributing to the object of these timbers are several others, called by the various names of "transoms," "fashion-pieces," &c., most of which assist in forming the connexion between the head and stern and the side-timbers. Many of the timbers are formed of two or more pieces joined together; and, being of immense weight, they are hauled up by pulleys, and supported by shores or poles until they can be adjusted to their places.

The first approach towards forming the body of the ship is made by laying down the "floor-timbers." These are pieces of wood laid side by side across the keel, and fastened down to it, except towards the end, where they are lifted from the keel by the interposition of timbers called "dead-wood," in order to make the floor of the ship curve upwards from the middle towards the ends. Then, springing from these and from the keel are the side timbers, which form the ribs of the ship. These extend up to the very top of the hull; and as the height is too great and the curvature too deep for any one timber to form a complete rib from the keel to the top, many timbers are joined together end to end for this purpose. Each timber so em-

Fig. 169.—The "Sovereign of the Seas," built by Charles I.

Fig. 170.—Ship-building Yard.

ployed is called a "futtock," or "foot-hook;" and the various futtocks for one rib, called the "first," "second," "third," and so on, together constitute a "frame of timbers." If the ship is small, all the pieces to form one "frame" are bolted together on the ground, and raised collectively into their place by means of pulleys; but in a large ship this "frame of timbers" would be too ponderous, and it is therefore raised in two or three masses. All the various

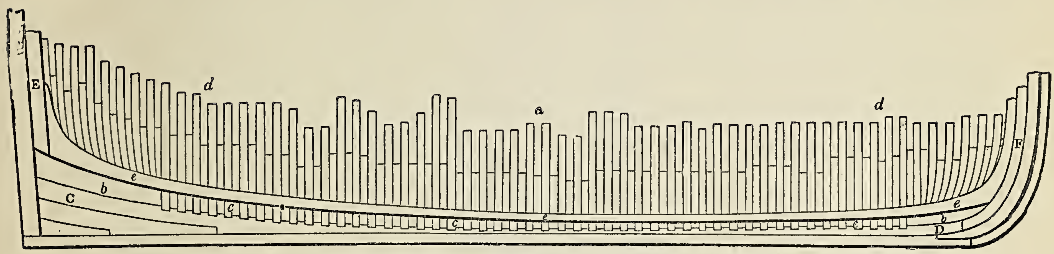


Fig. 171.—Section of a Wooden Ship's Timbers, from Stem to Stern.

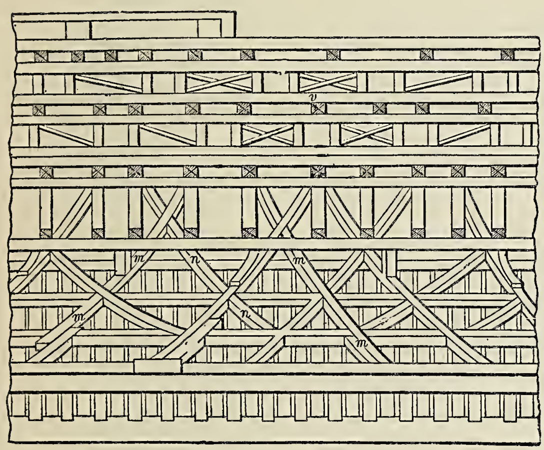


Fig. 172.—Timber Framing of a Ship.

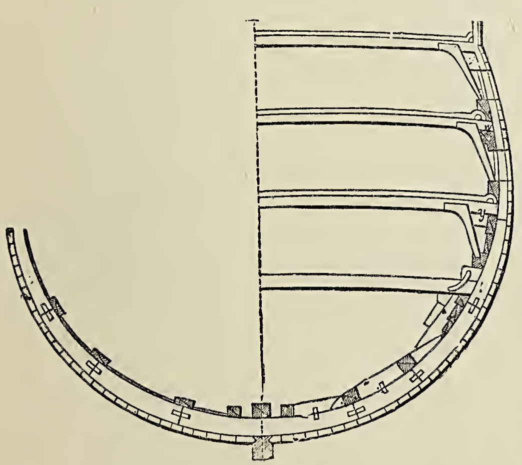


Fig. 173.—Transverse Section of a Ship's Timbers.

pieces are bolted together, end to end and side by side, so as to support each other; and thus operations go on, each "frame of timbers" being raised and adjusted in its turn, until the whole length of the vessel is rudely formed. They are supported externally by planks called "ribbands," and internally by beams stretching across from side to side.

In the state to which the building has now arrived, it presents internally the appearance presented in Fig. 175 where the eye is supposed to be placed about the middle of the vessel withinside, and to be looking towards one end; the keel, the floor-timbers, and the various rib-timbers being visible in their respective places. In Fig. 171 we have it under a different aspect. Here the ship is supposed to be cut down the middle from end to end, so as to show the relative positions of the timbers. At the bottom is the keel, from whence the "sternpost" rises at one end, and the "stem" at the other; at the level b are the "floor-timbers," and C D is the "deadwood" interposing between them and the keel; d d are the ribs of the vessel; e and E and F are three pieces designed to strengthen the keel, the stern, and the stem, and called respectively the "keelson," the "sternson," and the "stemson."

The "beams" of a ship are the bulky timbers which stretch across from side to side, serving both to retain the hull in its proper shape and to support the decks. If the vessel be a small one, a single timber will form a beam; but if it be large, three timbers are scarfed together, end to end. There are thirty or forty of such beams under the main-deck of a large ship, each one being so curved as to present a rise in the centre, amounting to about one inch to a yard. They are supported in the middle by pillars or vertical beams, and at the ends by various fastenings called "clamps" and "knees," some of which are of very ponderous character. Besides these beams,

the framework of a ship requires for its support numerous diagonal "braces," or pieces, either of iron or of wood, fixed in various directions on the inside of the main timbers, so

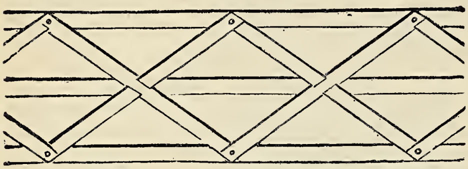


Fig. 174.—Diagonal Bracing of a Wooden Ship.

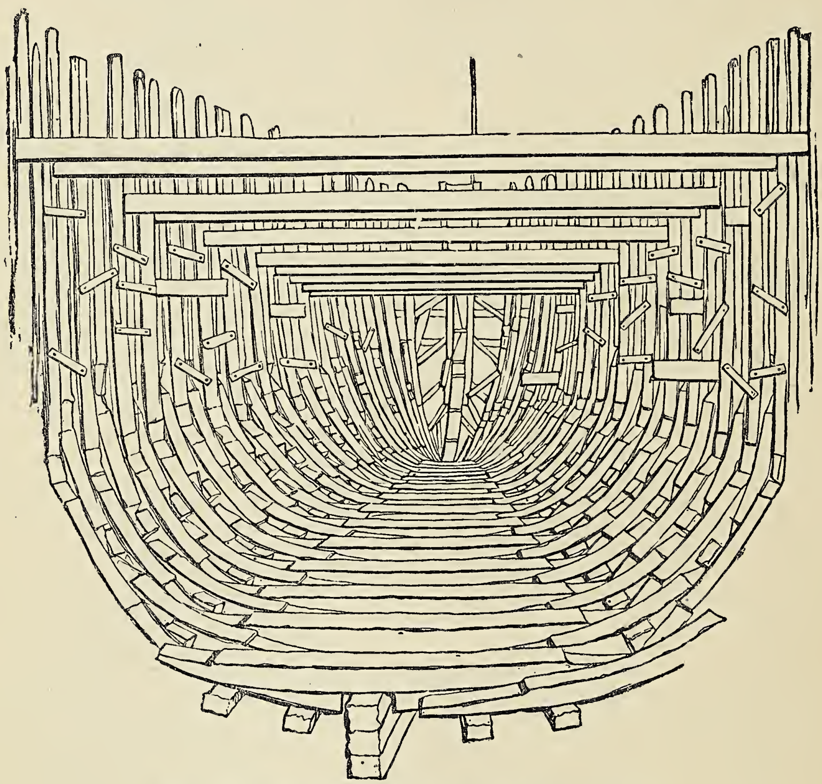
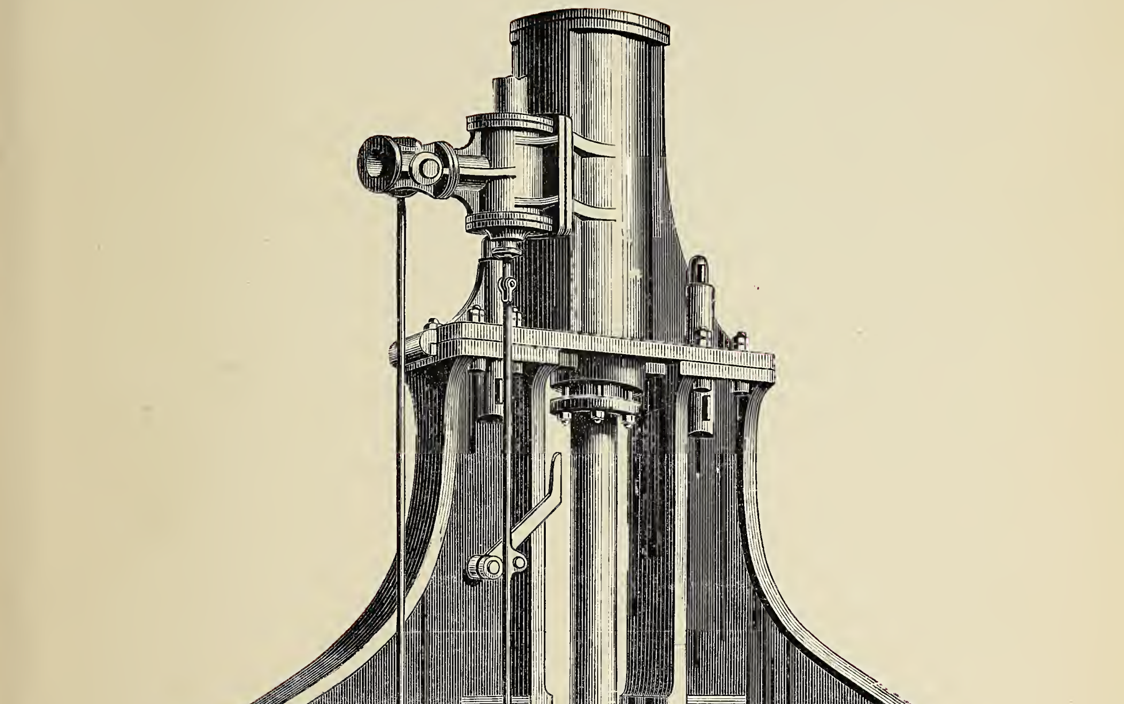


Fig. 175.—Frame-Timbers of a Ship, while Building.

as to avoid as much as possible their yielding. This is a very important feature in naval architecture, to which the attention of scientific men has long been directed. Figs. 172, and 174, give two examples of this interior strengthening; the latter being the diagonal arrangement of the strengthening pieces, and the former the complex intersection of the whole when put together. At Fig. 173 we have a cross-section of a vessel; the left half of which shows one of the ribs with its interior and exterior casing; while the other half exhibits in addition the beams and strengthening timbers of the ship.

When the heavier parts are thus completed, the ship is lined within and without with planking, thin in comparison with the main timbers, but still of considerable thickness; the planks are made of oak, they are in some cases thirty feet long, and their thickness varies from three to six inches. As they are laid horizontally round the hull of the ship, and are required to conform to its curvature, they undergo a bending process before being fixed on. They are in the first place cut at the saw-pit pretty nearly to the right length, width, and thickness; they are then trimmed with an adze to give them the proper contour; and they are afterwards placed in an oblong trunk or case where they are exposed to the action of steam for several hours. Softened by this steaming, they are in a condition to be bent round the vessel, and kept close to the timbers by powerful screws and other instruments; every plank being so shaped as to fit closely to the one adjoining it; and all of them becoming narrower towards the ends than at the middle.

The mode of fastening these planks to the timbers is not among the least important of the arrangements. While the plank is being held up in its place by screws, a man mounts on a scaffold (Fig. 176) and bores holes with an auger; these holes are from one to two inches in diameter, according to the thickness of the planks, and are bored not only through the plank, but also through the main timbers and



STEAM-HAMMER FOR FORGE WORK.

through the inner planking. The labour of boring them is hence very severe, especially near the keel, where the man has to work nearly over his head. Into some of these holes bolts of copper or iron are driven; but the greater number of the holes are allowed to remain open for some time, that the wood around them may season, and then large wooden pegs called "trenails" are driven in. These trenails are cut out of sound oak, either by machines or by men who work with sharp tools (Fig. 177), and are made from half a yard to a yard in length. Each trenail is slightly larger than the hole into which it is to be driven, so as to bite or hold firmly, and very powerful blows with a large hammer are required to drive it into its place: it is slightly longer than the depth of the hole, and the two ends are cut off after the driving. Finally, wedges are driven in at the ends, to tighten still more the trenail in the hole.

As a means of preventing water from entering between the planks, the seams are "caulked," or filled up by strings of "oakum." This oakum consists of old cables and ropes cut into pieces and picked asunder so as to form a mass of fibres: these fibres are rolled together as a kind of rude substitute for string, by means of the hand and a board placed in a sloping position. The threads of oakum thus rolled are made up into bundles, and taken to the ship's side, where the caulker proceeds to use them. He drives in the threads by means of a hammer and an instrument called a "caulking-iron" (Fig. 178), filling up every seam so densely that it not only prevents the entrance of water, but also strengthens the framework generally. Any little rents, holes, or fissures that may appear in the woodwork are similarly filled up with oakum. After this the whole is coated with a hot mixture of pitch and resin. This method of caulking is very ancient, as already mentioned at the commencement of this chapter, page 219.

While the main framework of the ship is thus progressing, many of the internal arrangements are also in hand. The decks, corresponding to the successive floors of a house, divide the internal area of the ship into compartments, one above another, and each deck is supported on one particular set of beams. We have explained, in an earlier page, that in a man-of-war there are three entire decks from end to end, besides two or three partial decks; but in smaller vessels the number is fewer, two whole decks and one partial deck being the utmost required in merchant-ships. Decks are generally made of fir, brought from Memel or Dantzic: the planks, varying from six to ten inches in breadth, and from two to four in thickness, are laid down parallel and fitted together with great nicety, the seams being coated with pitch and resin, to exclude wet. Besides the decks themselves, and the beams on which they are laid, there are numerous pieces of wood, called "partners," "coamings," and "carlings," placed at and around the various openings which are necessary in the deck of a vessel.

Without stopping to describe the multifarious arrangements connected with the ladders, the cabins, the berths, &c., all of which partake more or less of the character of joinery, we will pass on to notice those very important parts of a ship's fittings, the *masts*. Whether there be three masts for a large ship, or two for a brig or schooner, or one for a sloop or smack, the mast is never (except for a very small vessel) formed of one single piece of wood: it is built up of two or more pieces raised one above another. Take the mainmast of a ship-of-war, for instance: this is formed, in fact of four masts, of which the lowest is the "lower mast," the next the "top-mast," the third the "top-gallant-mast," and the fourth the "royal." The length of the lower mast is generally rather more than that of the others put together; and the entire length of the four exceeds in some vessels two hundred feet. In a large merchant-ship the lengths of these component parts of a mast vary from twenty to ninety feet; the longest being the lower-mast of the main-mast, and the shortest the "royal" of the mizen-mast.

Not only is each mast formed of several pieces in respect to length; but the diameter is often so great that no tree can be met with fitted to make it; and hence it is built up in thickness as well as in length. The principal part of the mast is made of Canadian fir; and the various pieces by which its bulk is made out are designated by the rather odd names of "spindles," "cheeks," "fillings," "cant-pieces," "heel-pieces," "side-trees," "front-fishes," and "side-fishes." All these pieces are shaped by means of the saw, the adze, and other tools; and are fitted together by various kinds of joints. So numerous are the pieces, and so bulky the whole mass, that (without going to the instance of a first-rate ship of war) it will be sufficient to state that the lower main-mast alone of an East Indiaman weighs upwards of six tons. As a means of retaining all the component parts in their right places, a number of stout iron rings are driven on the mast. These hoops are made of strips of iron bent round into a circular form, and welded; they are slightly smaller than the diameter of the mast, and are heated in a kiln previous to use; by the heating they are expanded, and in that state they are placed over the mast, and are driven on it in a very singular manner. Six men grasp the long handle of an iron bar, with which they strike the edge of the hoop on one side of the mast, while six others do the same on the other side with another bar; and two other men give powerful blows with hammers on the surface of the hoop. Signals are given to ensure regularity of movement, and the whole scene presents a singularly busy picture (Fig. 179). As the hoop contracts by cooling, it holds the mast together with enormous force.

The "bowsprit," the "yards," and the booms" of a vessel are long spars, partaking in some respects of the general character of masts, though in a smaller degree. They are arranged in a ship in various positions, and serve to retain the rigging and sails in a proper position. The largest "yard" in the largest ship is a hundred feet long, by two feet diameter at the thicker end.

In fixing a mast into a ship there are two modes adopted; either by means of "sheers" or of a "sheer-hulk." Sheers is the name given to an arrangement of poles or spars built up on the deck of a ship, and meeting in a point over the hole where the mast is to be lowered into

Fig. 176.—Boring "Trenail" Holes in Ship's Planks.

the hull of the vessel. The mast is floated to the side of the ship, elevated by means of tackle attached to the sheers, and lowered into its place, where everything has previously been prepared for its reception. When one of the masts has been thus placed, the sheers are

Fig. 177.—Making "Trenails," or Oak Pegs.

removed to other parts of the deck, and the other mast or masts fixed in a similar way. The other method is by the aid of a "sheer-hulk." This is an old worn-out ship, cut down to the lower deck, and provided with numerous masts, poles, ropes, and tackle, for hoisting great weights; these masts bend over one side of the hulk, so that their summits may be perpendicularly over the spot where a mast is to be lowered into another vessel. This latter is brought up to the side of the hulk; the mast is elevated by tackle to a sufficient height, and is then lowered into its place. In some places,

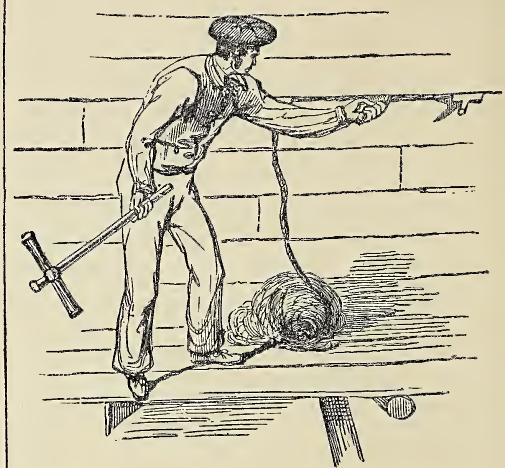


Fig. 178.—Caulking Ship's Planks with Oakum.

there is a masting-house provided with similar means of lowering a mast into any ship placed beside it; but the general method of proceeding is much the same as in the other two modes; the object being to lift up the mast vertically to a sufficient height before lowering it into the hold of the ship.

The masts here spoken of as being lowered in this way are not the entire masts in their whole height, but only the first portion, called the "lower-mast," whether "fore," "main," or "mizen." The "top-masts" are not adjusted to their places till a later stage in the proceedings. The lower-mast is adjusted and secured in its place by shrouds and ropes of different kinds; and when thus fixed, the top-mast is raised upon it. The two, however, do not join end to end in the same vertical line, the top-mast being placed a little in front of the lower-mast. Near the spot where the two meet there is a horizontal platform called the "top," which has openings to receive the upper end of the lower-mast and the lower end of the top-mast; the two masts do not actually touch in any part, but both are secured firmly to this horizontal "top" and to the rigging of the ship. The "top-gallant-mast," and "royal," when the ship has them, are raised above the top-mast in a similar manner; other horizontal platforms or "tops" being placed at the two upper, as at the lower stage.

Another important feature is the *sheathing* of a ship, generally effected after it has been launched. This sheathing is a coating or envelope put over the whole external surface of the vessel exposed to the action of water. Not only would the woodwork be liable to injury by

such exposure, but so much ooze, seawood, and shells would attach themselves to the bottom, that the speed of the vessel would be materially lessened. Various means have been adopted of producing this sheathing. Planks of deal or fir, sheet-lead, brown paper coated with tar—all have been used at different times and in different countries for this purpose ; but sheet-copper, or a mixed metal in which copper is one of the components, such as Muntz's metal, is found to be the best suited for this object.

The copper, or alloy of copper and zinc, is in the first place brought to the form of sheets, generally about four feet long by fourteen inches wide, having an average weight of about a pound and a half to the square foot. These sheets are nailed to the bottom of the vessel with nails made of the same metal ; being sometimes nailed to the bare planking, and at others to an interposed layer of sheathing-board of felt or of paper previously coated with melted pitch and tar. The copper sheets are pierced with holes by means of a machine, not only all round the edges, but at intervals of three or four inches over the whole surface. The edge of each sheet laps about an inch over the adjoining sheet ; and the flat-headed nails with which the whole is fastened are driven in regular order over the entire surface of the ship's bottom. Eight or ten thousand square feet of coppering are required for a merchantman of large size ; and such coppering is soon worn out. The chemical action of the sea-water, friction, concussion, and other causes produce this result. The old copper or alloy is melted down to form new sheets or sheathing ; and the new coppering is applied to the vessel in the same way as before.

We have so far traced the wooden-ship in its construction only as a parallel to the iron and steel ship-building, shortly to be described. In fact, the actual construction of an iron vessel differs from that of wood, chiefly in the material employed and the mode of fixing it together. For example, sheets of iron take the places of planks of timber, the ribs of the iron vessels are, of course, made of that metal. In place of trenails, &c., iron rivets are employed, and so we may go on in showing the similarity, at all events, the analogy existing between the wood and iron ship.

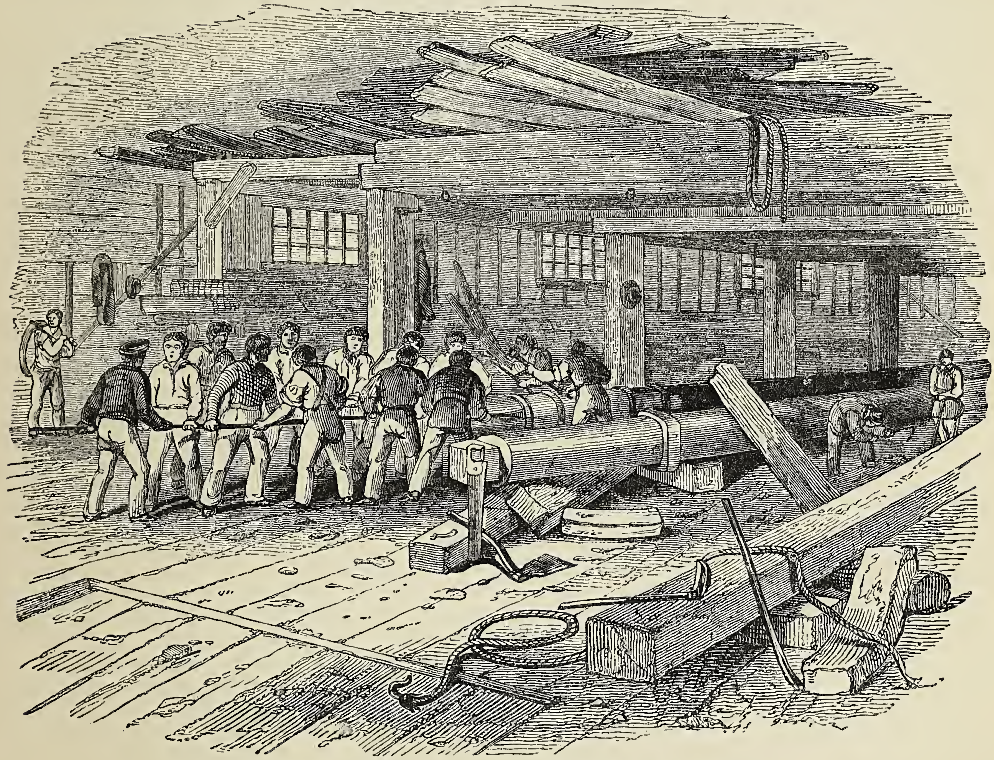


Fig. 179.—"Hooping" a Mast, or Driving on Iron Rings.

The ropes, sails, cordage, &c., of the wooden vessel (now replaced as in the masts by iron), will be fully dealt with in a subsequent chapter on textile manufactures, and, therefore, we shall now only make some remarks on anchors and chain cables, which are in common use in all kinds of large vessels. One of the most important requirements on board a vessel is a good anchor.

Anchors, as is well known to everybody, have

in general two arms or blades springing from a central stem (Figs. 180, 181, and 182), and so formed as to dig deeply into the ground when fittingly placed for that object. Before the modern anchor was invented, large stones, basket of stones, logs of wood loaded with lead, sacks filled with sand, and other contrivances, were adopted; but nothing has been found so efficacious as the fluted anchor.

In various kinds of ships, placed under various circumstances, many forms of anchors are employed. Boats and small vessels employ *grapnels*, which consist of five or six hooks arranged round in a circle, so that one or other of them is pretty sure to catch in the ground. The *mooring* anchor used for securing vessels in a harbour is simply a very ponderous body lying at the bottom of the water, to which the ship may be attached by a rope or chain, by a buoy floating over and attached to the mooring anchor. An enormous block of stone, or several stones fastened together, or one of the very largest anchors after it has been disabled for other use, are often used for these purposes.

But the anchors properly so called are those which are carried in a ship, and are hurled out from her when the ship is to be brought to a stand. Several of them are carried in all ships of any magnitude; in a "first-rate" there are as many as seven; while in brigs and schooners there are three or four. The names of "sheet-anchor," "bower-anchor," "stream-anchor," "kedge-anchor," are given to the several anchors of a large ship, each having its own particular duty to serve. Some of these are of most enormous bulk and weight.

The making of these ponderous masses is a remarkable branch of mechanical art,—one which has within the last few years received great advancement from the use of machinery. The several parts of an anchor are made separately, and then welded together; the shank, the arms, the palms, the ring—all being made of large masses of iron. In Figs. 180 and 182, *a* represents the arms, *b* the shank, and *c* the stock; but in Fig. 181 the analysis is more full: A is the ring, B the stock, K the arm, D*d* the throat, F the palm or fluke, B*b* the small, and H the bill or pea.

The shank, or long bar, which constitutes the main part of the anchor, is usually of such great thickness that no ordinary single bar of iron could produce it; and, therefore, in the common modes of anchor-making, it is built up of several smaller bars. For instance, in forging the shank for a large anchor, four iron bars are laid together in a group; on each side of this square are laid a greater number of smaller bars; outside these are others shaped something like the staves of a barrel; and exterior to the whole are a number of hoops binding the mass together. Then the whole being brought to a white heat in a furnace, ponderous hammers are employed to weld them into one homogeneous mass. This process has something picturesque about it. The anchor-smith's hearth is so filled with coals or fuel as to envelope a part of the anchor-shank with flame and heat on every side: the shank is sometimes nearly twenty feet long, and as only so much of this is heated at once as can be welded before cooling, the fire is arranged so as to heat this portion only. After being exposed to a fierce heat for half an hour or an hour, the ponderous mass is drawn out of the fire by means of a crane, and placed with the heated part upon an anvil. Eight or ten men then range themselves round the glowing mass, and strike in succession with hammers weighing about sixteen pounds each; a fireman points with a rod to the spot where the blows are to be given, while another man is ready with a long bar to turn over the shank when necessary. At the present time the process is modified by the use of the steam-hammer, and furnaces specially constructed for this purpose. Anchor-making in fact is a trade of its own speciality.

Without detailing many minor improvements, it will be sufficient to mention the form of anchor devised by Mr. Porter. In anchors generally the palms or blades are arranged in a curved position at the lower end of the shank; and when hurled or let go from a ship, it pitches on the ground with the shank pretty nearly vertical; it presently falls over, however, and in so doing settles with the point of one of the palms downwards, in such a way that the latter can dig into the ground, and hold the vessel fast by the intervention of the cable to which the anchor is attached. In Mr. Porter's anchor, on the contrary, the two arms or blades are connected to the shank by a swivel, so that they can swing to and fro. The objects to be obtained were principally these two: the avoidance of "fouling," or the passing of the cable over the exposed point of the anchor when fixed; and the avoidance of injury to the vessel itself in the event of falling upon her anchor. In anchors generally one fluke or point stands nearly upright when the other is immersed in the ground, and much mischief occasionally arises from this source. In the swivel-anchor, on the contrary, directly after it strikes the bottom of the sea, the swivel or hinge enables it to assume the position A (Fig. 183); the slightest movement of the cable suffices to disturb this position, and to bring it to the position B; lastly, the lower part, by penetrating into the ground, brings the anchor to the position C, with the upper peak lying out of harm's way on the shank, and not exposing a dangerous point as in the common anchor, as shown in the dotted lines.

But, whatever be the form of anchor, the process of "heaving" or drawing it up, requires arrangements of great magnitude and strength. When a rope cable is used, the circumference sometimes reaches the extent of twenty-five inches, and the anchor is weighed by means of a capstan, such as that sketched in Fig. 184; in which A is the cylinder of oak, strengthened by ribs or butresses B; at C is the top, or drum-head, with holes, *a*, for receiving the ends of the levers by which the machine is turned round; and at *b* are paulls for preventing the cylinder from slipping round the wrong way. In large steam vessels the anchor is now raised and lowered by steam power, and, as will be subse-

quently explained, steering and other operations on board are effected by the steam-engine.

An improvement in these matters has been introduced within the last few years by the use of "chain cables." The first incentive to the invention of these was the costliness of hemp during some period of the long war; but the excellence of the method, both as to charge and to efficiency, has led to its adoption on a very considerable scale. The liability of hempen cables to be destroyed, by chafing in rocky anchorage-grounds, sometimes occasions the loss of shipping; while the action of the sea-water upon hemp, and the alternate exposure to air and water, have a tendency to rot and weaken the fibres: these and other circumstances led to the suggestion of making cables of iron chain. It is said that the first idea of thus employing iron, occurred to M. Bougainville, during his voyage round the world, in 1776-7; but that no attention was paid to the suggestion till after the commencement of the present century. In 1808 Mr. Slater, a surgeon in the Navy, took out a patent for a chain cable; and soon afterwards the Admiralty ordered a trial of them to be made in the Royal Navy. Since that time successive improvements have been made in the form and structure of the chains; and the use of them has now become very extensive.

The chain cables now made consist of links from two to four yards long, fastened together by bolts. The withdrawal of one of these bolts effectually severs the chain; and this affords an easier mode of slipping or throwing off the anchor, in case of necessity in a perilous sea, than by the labour of cutting through a large hempen cable. Every link and component part in a chain cable is tested separately as to strength, before being used. The manufacture of chain cables will be further dealt with hereafter.

After having thus described the art of wooden ship-building, we next turn to the description of vessels of iron and steel, which, as already stated, have almost entirely superseded the use of timber.

In respect to the early history and progress to the present time of the use of those materials, abundant information has been given at page 212, at the commencement of this chapter.

Iron and Steel Shipbuilding.—In chapter III. we entered into full particulars of all the processes that have to be followed to bring iron into a malleable form to fit it for constructive purposes; and towards the close of that chapter steel was similarly dealt with. As far as laid in our power the most recent improvements were described in detail, or sufficiently, we hope, explained.

We have now to enter into a very important question, and one which has caused a great diversity of opinion among engineers, chemists, metallurgists, shipbuilders, and others. The question is—Can steel be safely and economically applied as a substitute for iron in the construction of large (especially steam) vessels, boilers, and other works of great magnitude? The prejudice against steel for railways is amusingly illustrated by an anecdote related by Sir H. Bessemer (page 98, *ante*) who, when he proposed to Mr. Ramsbottom, of the London and North-Western Railway, the substitution of steel for iron on that line, was met with the reply—"Do you wish me tried for manslaughter?"

But these prejudices against steel have, in some cases, been entirely banished, and in others to a large extent overcome. We cannot do better, in giving a general view of the state of the case towards the close of 1880, than quote the following remarks from *Engineering.* Into some of the details there mentioned, we shall enter more fully in our future pages. The writer remarks as follows:—

"That the application of steel for mercantile ship-building purposes is making steady progress was shown by the papers on the subject read at the meetings of the Institution of Naval Architects in March 1880, and by the discussion on these papers. Like most discussions, however, the one on steel went off upon one or two points to the exclusion of others of scarcely less intrinsic importance. It may not be amiss, therefore, to review briefly the present aspect of the question.

"There can be little doubt that shipbuilders are getting to understand the manipulation of steel far better than they did a year or two ago, and the sensational stage is getting left behind. If we compare Mr. Barnaby's paper (see p. 95, *ante*), read at the Iron and Steel meetings in 1878, with Mr. Denny's paper at the Institution of Naval Architects, it will be seen how marked has been the progress. At the former period the failure of a number of steel angles at Her Majesty's Dockyard, Chatham, had so far frightened the Admiralty authorities that a return to iron, at least for the frames of ships, was talked about, and even carried into effect. At the present time, Mr. Denny, after having used about 7,000 tons of steel, says, 'Indeed, our whole experience leads us to reverse the ideas largely held regarding steel and iron, and to look with confidence on the steel, and doubt on the iron. Our foremen and workmen hold this view of the matter very strongly and speak most contemptuously of going back to iron. Their confidence in the power of steel to do everything and stand everything, excepting working at a black heat, is of the firmest nature, and it will be acknowledged such confidence cannot be causeless.' This view was fully endorsed by Mr. H. Laird, of Birkenhead, by Mr. A. C. Kirk and others, who have largely used steel for shipbuilding, and nothing has come to light to show that the Chatham failures were due to other causes than unskilful manipulation under exceptionally trying circumstances.

"So long as the quality of steel is kept up to its present high standard of quality and uniformity, we are persuaded that every ship built of it will make partisans in its favour of those who adopt it, for between its properties and those of ordinary ship iron there is an enormous difference—wholly in favour of the steel. Mr. Denny stated that in a small steamer he was then building he had had to reject, for failure

under manipulation, more iron plates than the total number of failures that had occurred in the whole 7,000 tons of steel he had used. This quite bears out the experience acquired by such men as Mr. Webb of Crewe, Mr. D. Adamson, and others, who have been for years adopting mild steel in engine and boiler work.

"Next to finding favour in the ship-yard, steel has to find favour with the shipowner and the under-writer before it can take its place as the chief material for shipbuilding purposes. This again must be mainly a question of time and experience. Argument will be of little avail compared with the results of actual experience with steel ships which will be accumulating as time goes on, and as the number of steel ships afloat goes on increasing. We have already seen remarkable evidence of the increased safety of steel over iron ships when striking on rocks or in collision. The little steel steamer 'G.M.B.,' built by Messrs. Raylton Dixon and Co., in 1876, has been run into, and the frames and plating instead of being cut through as they would have been if of iron, were bent and curled up in a remarkable way, showing the extreme tenacity and ductility of the material. Mr. Laird gave an account at the last meeting of the Institution of Naval Architects of a steel steamer, the 'Stormcock,' built by his firm in 1878, that struck a sunken object on the Irish coast, and dished up the plating about 8 inches, but without endangering the ship. Had it been an iron plate, he says, the opinion of all experts who have seen it is that a hole would have been knocked through it. Mr. Thornycroft who has had large experience of steel in small boats, says that his experience of collisions between these boats is greatly in favour of the steel. One of the most remarkable cases, however, that has yet come to light is that of the passenger screw steamer 'Rotomahana,' built in 1879, by Messrs. Denny and Brothers, for the Union Steamship Company of New Zealand, and the particulars of which were appended to Mr. Denny's paper. This ship was running at high speed with an excursion party on New Year's Day 1880, when she struck on a rock just under the foremost bulkhead of the boiler space. Had there been a hole knocked in the vessel at this part it would in all probability have opened the forehold and the engine and boiler space to the sea, and the ship would have gone to the bottom, probably with all hands. The blow was so severe that the bulkhead was corrugated to some extent by it, and the plating of the bottom was badly bent up for a length of 20 feet. A number of the frames were also badly bent 'with a sharp curve tending both inwards and aft.' The ship, however, remained water-tight and intact. The vessel was placed in dry dock, the bent plates taken out and restraightened in the rolls, the frames heated and brought back to their form and the original plates put back into place, and the vessel again afloat and ready for work the third

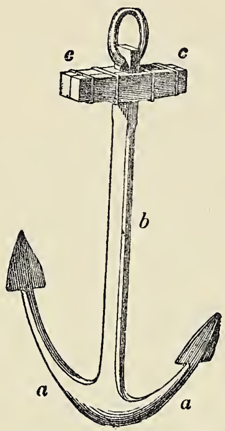


Fig. 180.—Anchor.

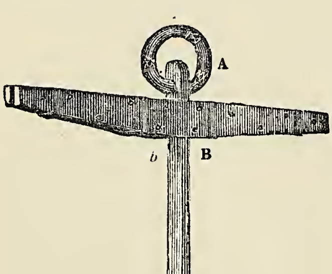


Fig. 181.—Anchor.

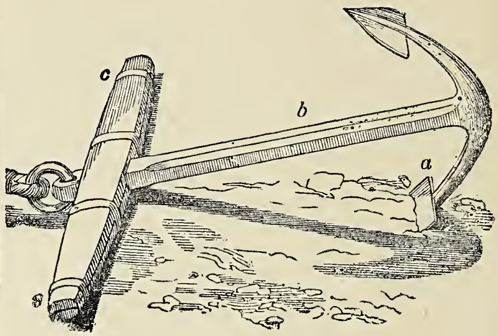


Fig. 182.—Anchor.

day after. The managing director of the company writing on the subject, says:

"'This experience has shown clearly the immense superiority of steel over iron. There is little doubt that had the "Rotomahana" been of

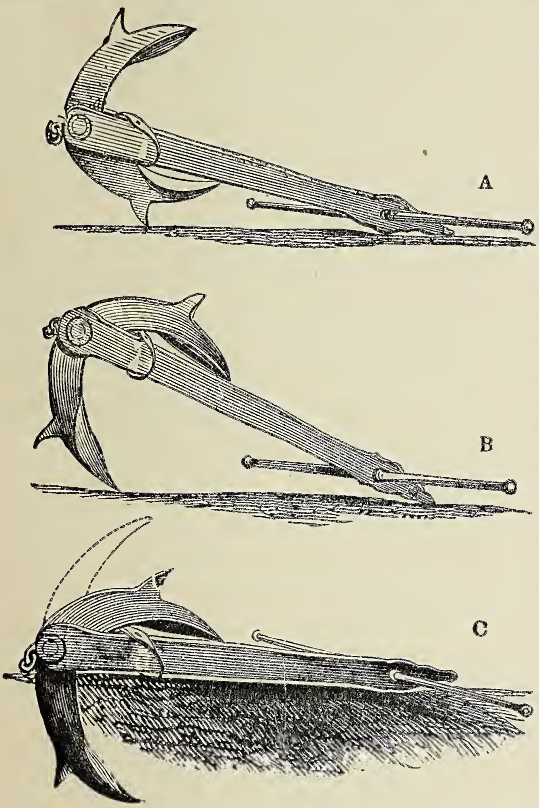


Fig. 183.—Porter's Swivel-Anchor.

iron, such a rent would have been made in her that she would have filled in a few minutes. A number of frames were set back by the force of the blow, the bulkhead was bulged and the plate

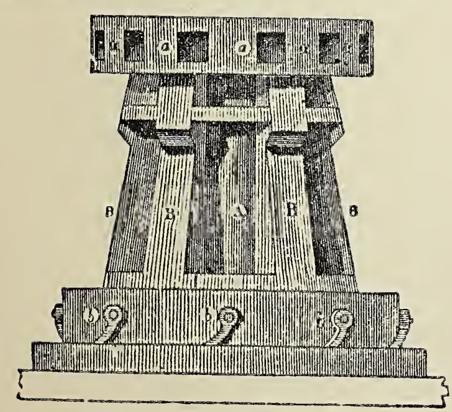


Fig. 184.—Capstan for Ship's Cable.

was corrugated, and yet there did not appear one crack anywhere. We would, however, require better tools than we have at present if we are to have anything further of this nature, as the steel proves very difficult to work.'

"A still more remarkable case perhaps is that of a light steel river boat that got her bow fixed upon a sandbank recently, and although the tide left her, and the bow was forced up some feet, the vessel made no water, the steel skin remaining intact, whereas an iron boat would have broken in two.

"There is no reason whatever to suppose that these cases are exceptional, or that accidents of one kind, and another will not happen to other steel ships afloat, tending still further to demonstrate the greater safety of ships built of a material so much superior to iron in every quality of strength, uniformity and ductility.

"When this point becomes clear, many old prejudices will vanish that have done much to impede the adoption of steel. That the price of steel will prove a permanent obstacle we do not for a moment believe, for in spite of the present limited power of production, the prices of steel and iron have been on the whole approximating to each other, and with the further development of steel works, and a healthier competition, still further progress in this direction may be expected. Indeed there can be little doubt that at the present time the limited output of steel is the chief obstacle to its extended use. Builders cannot insure having the material delivered rapidly, and rather than risk delay they prefer to build in iron, and so far as they can, they influence owners in the same direction. Perhaps the two most important practical points that require discussion at the present time are (1) the question of rivetting, and (2) the limits of tensile strength that should be adhered to. These points were raised at the Naval Architects' meetings, but were not by any means disposed of. At the meetings just mentioned, Mr. Denny urged, from the results of some experiments on the shearing strength of steel rivets, that as the shearing strength of steel is considerably below its tensile strength, while in the case of iron the shearing and tensile strengths are more nearly equal, therefore the rivet area should be greater in proportion to the area of the plates in steel than in iron ships. At present the practice is to make the size and spacing of rivets in a steel ship the same as they would be in an equivalent iron ship of heavier scantlings whether the rivets are of iron or of steel. It may, of course, be urged, that this being so, steel ships are at least equal in strength, so far as the shearing of rivets is concerned, to iron ships, even if iron rivets are used. Still more so then are they stronger in this respect where steel rivets are used, for experiments show that steel rivets are stronger in shear than iron ones, in spite of the disparity between the shearing and tensile strength of the steel.

"Beyond this, however, is the question whether by increasing the rivet area in steel ships still further they will not be materially improved. We are inclined to think they will, as by this means the superior strength and quality of the steel can be fully developed, and instead of being on a level with iron ships in point of strength they can easily be made stronger than they are, while preserving the reduction of 18 or 20 per cent. usually saved in their scantlings.

"It must never be lost sight of, however, that closely associated with this question of rivet area, is the question of the loss of strength in steel due to punching. This is of quite equal importance to the rivet area, and in the discussions to which we have referred it scarcely received the prominence due to it. It is still one of the comparatively unknown factors in steel ships, at least except with the mildest kinds of steel.

"Its importance is seriously enhanced when attempts are being made to push up the limits of tensile strength for shipbuilding steel to 35 or 36 tons per square inch instead of 30 or 31 tons as a maximum limit. The mild steel of which we have had the experience of the French and English Admiralties, has nearly all been between the limits of 26 and 30 tons per square inch. And this is within a ton or two of the limits adopted in the merchant service since mild steel was introduced a few years ago for shipbuilding. When therefore it is proposed to take a new departure and fix the limits between 30 and 35 or 36 tons per square inch it must not be forgotten that this is practically throwing away the experience above alluded to, and in fact shutting out the very material that has been steadily for some years growing into public confidence. We would not advocate for one moment keeping down the limits of strength of steel one ton below what it can be relied upon for safe working under the rough usage of the shipbuilding yard, but we should much regret to see it thrown back again by too rapid an advance, into the 'fear and trembling' stage. There is a great future before mild steel if it is only allowed to work its way cautiously and prudently into public confidence, and those most interested in it should be the first to deprecate any hasty advances in hardness and temper, and more especially until more is known than at present concerning the question of butt joints, the loss of strength due to punching, and the possible dangers of working the harder kinds in severe weather, the effect of variations of heat on its temper, and the necessity for annealing after punching or resorting to other expedients, such as drilling or rimering to keep the strength and trustworthiness of the material unimpaired."

It will thus be seen that many conditions have to be satisfied before an actually safe steel can be adopted in shipbuilding. At pages 106, 107 and 108, we have given tables showing experiments of a crucial kind on some sorts of steel. We are indebted to the pages of the *Iron and Coal Trades' Review* for the following information published in that journal in 1881. It relates to the meeting of the Iron and Steel Institute held at Düsseldorf in 1880, and treats on the Cockerill mild steel used for ship-building.

"The Société John Cockerill possesses, besides their steelworks at Seraing, which were visited by about fifty members of the Iron and Steel Institute on their return from the Düsseldorf Meeting, some ship-building yards at Antwerp, where they have lately been turning out some steel vessels, about 2,000 tons burden, for fetching iron ore from Spain for their own consumption. In order to get these vessels classed, they applied to the Bureau Veritas, which on the Continent answers to Lloyd's in this country, and which was founded in 1828 for giving technical information by way of guiding marine insurance companies. The Bureau Veritas does not insure vessels, but only classes them on its register. It is the practice, not merely to survey the vessels on completion, but also to test the materials during construction. For this purpose they have erected, at their head office in Brussels, a Thomasset testing machine, to which some additions have been made by their own engineers. In its present form the machine consists of a force pump, the plunger of which is screwed down gradually into the barrel by means of two sets of gear, one multiplying six times, and by which a lad can put on a pressure up to 25 tons. The pump is put in communication by a small copper pipe, with a horizontal hydraulic press• so that the pressure acts on the front of the ram, for pulling the test piece apart. The ram having a jaw cross-head at one end for holding the sample, is made hollow so that it can be adjusted by a screw and hand wheel at the back end, to suit the length of the piece to be tested. The other jaw is put in connection with a crank lever hung on knife edges, so as to reduce to a minimum all error due to friction; and the other end acts also through a knife, on a cover, pressing through an indiarubber diaphragm on water contained in a very shallow cylinder. The pressure of the crank lever, the two arms of which are in the proportion of about one to five, is communicated through a copper pipe to a mercurial gauge divided by 50 kilogrammes (1 cwt.) up to 25 tons. A sector, graduated to millimetres and halves, but six times the actual size, is clamped to one end of the test-piece, and to the other is clamped a brass ribbon, working the index, provided with a vernier at the point. It thus happens that when the sample is being pulled apart, the elongation can be read off the scale correct to 1-20th of a millimetre. Indiarubber buffers are introduced between the ends of the sample and the jaws, for deadening the shock on fracture.

"We were invited to attend the experiments carried out on a series of plates produced by the Cockerill Company for use in their Antwerp ship-yard, and which extended over several weeks. The tests were conducted by the engineer to the Bureau Veritas, under the direction of M. Résimont, superintendent of the rolling mills and steam hammers at Seraing; Mr. Edward Barrow, managing director, and M. A. G. Schaeffer, surveyor, Bureau Veritas, also being present from time to time. This company

admits steel for shipbuilding from 26 to 32 tons per square inch, the higher limit being thus equal to that recently adopted by Lloyd's. The steel experimented upon was that of extra mild quality, made expressly for the plates and angles of vessels. A charge of six tons, consisting of half charcoal pig and half pure hematite pig from Cumberland, is melted in the cupola so as to give a sufficiently hot but not over heated, metal. This is blown in the Bessemer converter from fourteen to fifteen minutes with a relatively cold working, so as to burn the silicon and generally to eliminate the impurities. Towards the end of the 'blow' from 1 to 1½ per cent. of ferro-manganese, containing from 55 to 60 per cent. of manganese, is charged in cold, at two or three separate times, so as to avoid oxidation, and utilise all the manganese. There is no over-blow, which has the effect of introducing oxide of iron and generating gas, thus giving rise to blow-holes. From a sample taken out a bar, 20 m. m. (three-quarters of an inch) square, is made, and is bent cold, so as to afford an indication of the degree of hardness possessed by the metal; more ferro-manganese is added, or not, according to the result and the purpose for which the steel is required. In this respect, therefore, the Cockerill Company assimilates the Bessemer to the Siemens-Martin process. The sample bar, quenched in cold water, is also nicked and broken, so as to afford, by the appearance of its grain, a further indication of the nature of the metal. The steels are classed, according to their hardness, as 0, 1 soft; 1, 1 hard; 2, 2 hard, and so on, up to 6; but practically, only four classes are made in commerce. From each pour a small ingot is run, which is rolled into a plate, and from this, as nearly as possible at a quarter of its length from each end, two test pieces are taken, one in the direction of the rolling, and the other across the grain. These two pieces are carefully tested by extension; a small quantity is analysed for the carbon; and in the case of extra soft steel for plates a quantitative analysis is also made for the carbon, silicon and manganese. All steel that is not found to come within the following limits, is regarded as unfit for shipbuilding, and is used for some other purpose :—

Carbon	.	0·08	to 0·15	per cent.
Silicon	. . .	trace	,, 0·02	,,
Sulphur	. .	0·03	,, 0·05	,,
Phosphorus	.	0·03	,, 0·05	,,
Manganese	.	0·30	,, 0·60	,,

"The samples tested by the Bureau Veritas were wrought to the ordinary form, with a length of 200 centimetres (eight inches) independently of the ends by which they were held. The edges were planed and afterwards draw-filed, with the arrage removed by emery cloth, because, in the same way that an iron bar is easily broken after being nicked, a very small inequality is sufficient to determine premature rupture.

"Altogether seventeen samples of the same mild steel were tested, three angles and the remainder taken in about equal proportion in the direction of the rolling and across the grain. The breaking strain varied from 27½ tons to 31 tons per square inch, giving an average of 28 tons on the seventeen samples. The elongation varied between 18·6 and 25·2 per cent. on the length of 8 inches, giving an average of 22 per cent. The elastic limit, which is by far the most interesting item, varied from 16½ tons to 19½ tons per square inch, showing an average of 17·8 tons per square inch. In one case, a test piece taken in the direction of the rolling of a sectional area of nearly ½ square inch, broke with a stress of 31 tons (the maximum of the series), and also showed the highest limit of elasticity, that is to say 19½ tons. But the ratio of elastic limit to breaking strain was far from being constant, and the Directors of the Bureau Veritas appear inclined for the future to base their deductions in couplings of steel in the place of iron more upon the limit of elasticity than upon the ultimate breaking strain. The greatest amount of elongation 25·2 per cent., was observed in a test bar taken across the grain, of a slightly larger sectional area than the preceding; it also showed the maximum breaking strain and a high elastic limit, 18½ tons per square inch. Strange to say, it was also a transverse sample that showed the smallest amount of elongation, viz.: 18·6 per cent., while its breaking strain, and also it elastic limit were within half a ton per square inch of the maximum. The fact of a test piece having been taken in the direction of the rolling, or across the grain, does not appear to exert much influence on the amount of breaking and elastic limit, the average of the former being 28·7 tons per square inch for longitudinal, and 28·9 for transverse samples, and that of the latter 17·7 and 17·6 tons per square inch respectively; but the transverse plates give evidence of a slightly higher elongation, the average being 22·2 per cent., against 21·7 per cent. for the longitudinal. On the whole, the series of tests—which were carefully made and minutely recorded—prove the wonderful uniformity that can be attained with the new metal, which is doubtless destined ere long to supersede iron, as iron formerly succeeded bronze in early ages."

From the preceding quotation it would appear that despite all the opposition and prejudice that existed against the employment of steel for building ships of any amount of tonnage, and making steel boilers calculated to bear a very high pressure, that material has now come extensively into use. The year 1880 may be called, for all practical purposes, the first decade of its employment for such purposes, and as a matter of historical interest, and for the purpose of enabling our readers to have some accurate data by which the future of the use of steel may be compared, we quote the following from the *Iron and Coal Trades' Review*, being a report of "mild steel," shipbuilding during the year in respect to its great centre, the River Clyde, on whose banks, in the neighbourhood of Glasgow, every kind of iron and steel ship-building engineering &c. is carried on.

"First in order, then, we would remark upon

the rapidity with which 'mild' steel is coming into use upon the Clyde, and which is certainly one of the most important facts of the present time in connection with the constructive arts. Steel has been used to a certain extent in shipbuilding on the Clyde, and for the construction of marine boilers over a number of years; but it was only after the Steel Company of Scotland had got their great establishment at Newton, near Glasgow, into thorough-going order, and when the manufacture was brought to the very doors of the Clyde shipbuilders, that the demand for Siemens or 'mild' steel really set in with any marked rapidity. So long as the advocates of steel had to depend exclusively upon plates, angle bars, &c., made from the produce of the Bessemer converter, they could never be sure of the quality of the material that was at their service; but, in course of time, the firms or companies that resorted to the use of the open hearth process could guarantee such a degree of uniformity in the quality, including great tensile strength, that shipbuilders, shipowners, and engineers became inspired with such an amount of confidence in it that they forthwith showed their willingness to stake their reputations, their fortunes, and the safety of many thousands of sea-going travellers upon it. In the year 1879, the amount of shipping turned out on the Clyde, in which steel was the material of construction, aggregated nearly 19,000 tons; last year (1880), however, the enormous total of 42,688 tons of steel shipping was constructed. Many Clyde firms have now cast in their lot with the spirit of progress, so far as the use of the 'shipbuilding material of the future' is concerned, but the following are some of the firms that have been most prominent in its use, namely, Messrs. John Elder and Co., Messrs. William Denny and Bros., Messrs. James and George Thomson, Messrs. A. and J. Inglis, Messrs. Barclay, Curle, and Co., Messrs. R. Napier and Sons, Messrs. Dobie and Co., and Messrs. Robert Steele and Co. Amongst the chief steel-built vessels launched on the Clyde last year we may mention the Imperial Russian yacht 'Livadia' (which we shall presently describe in detail), two steamers for the British and African Steam Navigation Company, one for the Peninsular and Oriental Steam Navigation Company's great fleet, four steamers for the fleet of the British India Steam Navigation Company and an Allan liner of great size and power.

"Up to the end of the year, and since the present kind of 'mild' steel came into use, Messrs. William Denny and Brothers, Dumbarton, had turned out steel-built shipping in the shape of sea-going and river steamers to the extent of 23,000 tons gross; and in order to construct that amount of tonnage they required to use 9,000 tons weight of steel, in addition to a certain amount of iron for what may be called the non-structural parts. The largest vessel built of steel by that firm was the 'Buenos Ayrean,' of 4,000 tons gross, for the well-known Allan Line of transatlantic steamers. The same firm has on hand 18,000 tons of steel steamers in course of construction, which will require for their completion something like 8,000 tons of steel. It is a most satisfactory thing for Messrs. Denny and Bros. to be able to say that no shipowners amongst their constituents who have once employed steel ever think of departing from it. That is certainly a very strong indication of the firm hold which steel for shipbuilding has taken upon the shipowning community. We had almost omitted to mention that the firm just named built no fewer than seven steel vessels last year, four of which were steamers ranging from 2,823 tons up to 3,340 tons. Messrs. James and George Thomson used about 6,000 tons of 'mild' steel last year, chiefly upon vessels which are still in course of construction, and one very large, namely, the 'Servia,' 8,500 tons; the 'Aurania,' 7,500 tons; and 'Catalonia,' 5,000 tons; and we are assured that steel would have been adopted for the 'Pavonia,' another vessel building by the same firm for the same owners, namely, the Cunard Company, had it not been that when she was contracted for there were apprehensions of difficulties arising in the delivery of such large quantities of steel. As it is, there are three large steamers, of about 20,000 tons measurement, being built of steel in one yard, and for one shipowning company. Such a surprising fact is one upon which both builders and owners may alike be congratulated, while it is also one that speaks volumes in favour of the use of steel in the future. It is scarcely necessary to give the details in reference to the other steel shipping that is on order or in actual course of construction in the other shipbuilding yards on the Clyde, still it is specially worthy of mention that Messrs. Dobie and Co. have contracted to build of steel three steamers of 5,000 tons each, for a new line of cargo-carrying vessels to trade between Liverpool and New York.

"Amongst the other evidences of progress of shipbuilding on the Clyde, we may mention the extensive adoption of the longitudinal bracket system of construction, by means of which there is obtained greatly increased longitudinal strength, and giving, if required, water ballast arrangements in the double bottom. The 'Buenos Ayrean,' the largest steel steamer in the mercantile marine, yet doing service at sea, is constructed on that system. The system of edge-to-edge plating, with butt straps fore and aft, instead of using filling pieces, is also coming into practice in several of the principal shipyards on the Clyde.

"Not the least point of interest and importance in connection with the use of steel in the construction of large steamers is the utilisation of steel scrap on a very extensive scale for forgings. We have the authority of Messrs. Denny and Brothers for saying that such forgings are undoubtedly much stronger than similar structures made of iron, and that they are very reliable. The firm just named have already sent to sea three steel screw ocean steamers, each of about 3,000 tons gross, the stems, stern frames, and rudders of all of which were forged entirely from scrap steel. One of the stern frames weighed thirteen and a half tons, and Messrs.

Denny have at present erected in Leven shipyard a stern frame weighing sixteen tons, which is likewise forged entirely from that kind of material. Such evidence of economic practice in respect of shipyard 'scrap' is deserving of the highest commendation.

"Mild steel is also coming into extensive use in the construction of marine boilers amongst the Clyde engineers, and the experience of those firms that have used it longest for the purpose is extremely favourable. That is especially true in respect of the use of steel inside the boilers. Most satisfactory reports have been received from abroad by one of the above-named firms regarding the steel insides of several iron boilers which they had constructed. As compared with similar insides, made of best Yorkshire iron, they are said to be almost entirely free from blisters. This is a fact which speaks very strongly in favour of steel, and one which, it is thought, will in course of time throw Yorkshire iron entirely out of use for such purposes. There is no doubt that the homogeneous and solid steel resists the action of fire infinitely better than is at all possible by a piled and frequently laminated material, such as Yorkshire iron, even of the highest quality sent into the market. There is good reason to believe that year by year the minds of engineers will be more and more firmly impressed with the greater durability of boilers having steel insides, and consequently with the greater economy in repairs. It may be said that there are some firms that would never dream of giving Yorkshire iron a preference over, or even an equality of comparison with, good mild steel for use in the insides of boilers. Out of thirty-eight boilers required for the Cunard steamers in course of construction by Messrs. James and George Thomson, no fewer than twenty-nine are being made of that material; and Messrs. James Howden and Co., Glasgow, have in hands about forty steel boilers, of which no fewer than thirty are required for the three steel twin-screw steamers already referred to as being in process of building by Messrs. Dobie and Co. Various other firms are also well supplied with orders for steel boilers for vessels now building. We ought likewise to mention that not only is mild steel being used extensively in the construction of the shells, furnaces, &c., of marine boilers, but the same material is now being used by at least one eminent Clyde firm in the form of corrugated flues, made on Fox's patent, and they are so confident of their success in actual practice that they believe this 'new departure' in boiler making will soon become general.

"With the growth of confidence in the use of steel for shipbuilding and boiler making, there has arisen a great demand for rivets made of the same material. The manufacture of steel rivets has been made quite a speciality by one well-known firm in Glasgow for several years, and last year's turn out of such goods by the firm was about 1,300 tons, exclusive of very large deliveries which, for special reasons, were made during the month of December, 1879. Steel rivetting is certainly more expensive than iron rivetting, but, with that exception, the workmanship on a steel steamer promises to be cheaper than that required on an iron one of a similar character. This circumstance is due to the greater reliability of the steel rendering a shipbuilder almost entirely secure against the waste of workmanship so frequently arising from the failures of iron plates, angle bars, &c. Another point that is worthy of attention in regard to steel is the generous limits allowed by steel makers, which are far in excess of those permitted by iron manufacturers, so far, indeed, that payments for 'extras' in weight or size are unknown in the building of steel steamers.

"We have already referred to the use of steel scrap in forging stern-frames, rudders, &c., but steel is also being extensively employed for shafts, and for other engine forgings. Whitworth's compressed fluid steel was used in one or two instances last year for propeller shafts, which were hollow in their structure; and steel made by Vickers, of Sheffield, and Krupp, of Essen, was also used for cranks and other parts of marine engines.

"Boiler pressures are being rapidly increased. Pressures up to 90 lbs. per square inch are not at all uncommon; even up to 100 lbs. is being reached in some instances. But very much higher pressures are to be used in the immediate future. For example, Messrs. Robert Napier and Sons are at present engaged on a steamer of large size for Messrs. George Thomson and Co., of Aberdeen, in which it has been decided to have a working pressure of 125 lbs. per square inch in the boilers; and the engines of course, are to be made suitable for the economical utilisation of that great pressure. They are to consist of three cylinders, respectively of 26, 42, and 70 inches in diameter, with a stroke of 54 inches, and the steam being expanded through them in succession. Then, again, in the case of the three large twin-screw steamers for which Messrs. James Howden and Co. are providing the machinery, the boilers, which are of the locomotive type, are also to have a working pressure of 125 lbs. per square inch; but the engines in this instance are to be of the type known as steeple engines.

"It is confidently anticipated that very high results will be obtained in both of the cases just referred to. Messrs. James and George Thomson are also building three-cylinder engines for their Cunard steamers, but they intend only to proceed the length of 90lbs. in the boiler pressures, the speeds contemplated being from 15 to 18 knots per hour, and they aim at attaining a consumption of coal not exceeding 1·7 lbs. per indicated horse-power per hour. Of course, there are some marine engineers that are not yet prepared to exceed 80 lbs. pressure in their engines, believing that by means of a longer engine-stroke and other structural modifications in the engines as great an amount of economy can be got as by using the higher pressures spoken of. Certainly the higher pressures of 100 lbs. and 125 lbs. per square inch cannot be fully utilised unless there is some re-arrangement of the engines through which the steam power is to be turned to account. We have no

doubt, however, that the Clyde engineers will be quite equal to the new condition of things that seems now to be entering upon its development."

Such is an account of the astonishing progress that steel has made as a material for shipbuilding and boiler-making during a comparatively brief period.

Amongst many vessels that have been named already as built of steel and furnished with steel boilers is the "Livadia," a steam yacht built in 1880 for the then Emperor of Russia, who however was destined never to use it, as he was assassinated at St. Petersburgh, in March 1881, while the "Livadia" was lying in Ferrol, having put in there towards the close of 1880, owing to the stormy weather she had experienced during her intended voyage from Glasgow to the Black Sea. We quote the description from a paper by Captain Goulaeff of the Russian Navy, read before the Fairfield (near Glasgow) Association of Engineers, and close to the yard in which the vessel was in course of construction, and just before she was launched. We are indebted to *Engineering* for the engravings of the "Livadia" which illustrate the description. The vessel itself is remarkable as being built on plans utterly opposed to all other ideas of shipbuilding of the present day, as regards shape, &c. We quote Captain Goulaeff's remarks *verbatim* as follows, after some preliminary remarks:—

"Being asked by your chairman to read a paper at this Institution, I could not refuse this offer, as I considered it a great pleasure and honour to be able to speak before the Fairfield Association of the 'Fairfield Child' (the 'Livadia.') But, in doing so, I must apologise at starting for my bad English, trusting you will excuse me, as my poor knowledge of your language comes only through my not being a Scotchman.

"It seemed to me more suitable, on this occasion, to describe to you the ship herself in as few words as possible, giving only her principal features, and the main objects which were in view in designing her, and to dwell largely upon the probable development of this class of ships, when adapted for great peaceful and beneficial purposes.

"This vessel is 235 feet long, 153 feet broad, and has a draught of 6 feet 6 inches. She might have been a little longer, but on closer investigation it was found that the addition of some 25 feet or 50 feet to her length would not have reduced the resistance in water. Augmentation of skin friction, not being sufficiently compensated by the improved lines, would have required increased power to drive the larger vessel with the given speed. She might have been a little narrower to suit the taste of most people, yet the beam of 153 feet cannot be regarded as being too great if we bear in mind the main object of her design, namely, the desire to secure the greatest steadiness.

"Her small draught is perhaps the most peculiar of her features. Experimental analyses, agreeing with actual results derived from the trial trips of extremely broad vessels existing in the Black Sea, prove that at certain speeds a very much broader vessel requires only half as much power compared with another vessel of similar form whose draught is double. This is represented on one of the diagrams (see Fig, 192 at a subsequent page). The upper curve shows the resistance of the circular vessel, 120 feet long, 120 feet broad, and drawing 13 feet of the same displacement as the yacht, whilst the lower curve represents the resistance of the yacht drawing 6 feet 6 inches. Hence the importance for the vessels of that class to have the smallest possible draught, and hence the anticipation that great speeds are not incompatible with this form. The late Mr. W. Froude, who conducted, at the request of Admiral Popoff, some experiments with the models of vessels of his design, was the first to demonstrate by exact data the influence of draught on the reduction of resistance. No doubt, such reduction of the total resistance, with the reduction of draught and the increase of other dimensions, is owing to a great diminution of the wave making; indeed, the diagram proves that the advantage of the shallow ship increases with the increase of speed, and, as you all know, at great speeds, according to Froude, the most important portion of the total resistance is the wave making. Such considerations and reasonings, agreeing, as I have stated, with actual trials of the existing vessels —one broader and shallower than another— determined the small draught which has been given to the yacht.

"Thus we see that, under the circumstances, the principal proportions of the yacht could scarcely be altered in any way to the advantage of the ship.

"Having specified the extreme dimensions, I will draw your attention now to the form of this vessel.

"The form of underwater portion was made a subject of very careful study. Besides the great experience of the designer of the ship, Admiral Popoff—experience which he derived by spending the greater portion of his lifetime, either on the ocean, or in constructing novel ships, and trying them at sea—Dr. Tideman, member of the Academy of Amsterdam, was invited to assist in the determination of questions connected with the resistance of the yacht.

"In the case of this shallow draughted vessel, the fine lines must be the vertical sections, whereas the fine lines of the ordinary steamer are the water lines or horizontal sections. Such change has been brought about by passing from long, narrow, and deep forms of ordinary vessels to the proportions of short, broad, and shallow ones; and, as has been demonstrated by experiments with paraffin models, the sharpening of buttock lines is more essential in this case than sharpening of water lines. In other words, if the motion of an ordinary vessel may be compared with that of a wedge propelled vertically, the motion of the yacht ought to be compared with the same wedge propelled through the water horizontally. On looking at the stern of the actual vessel you will observe that the whole motion of the water between the stern

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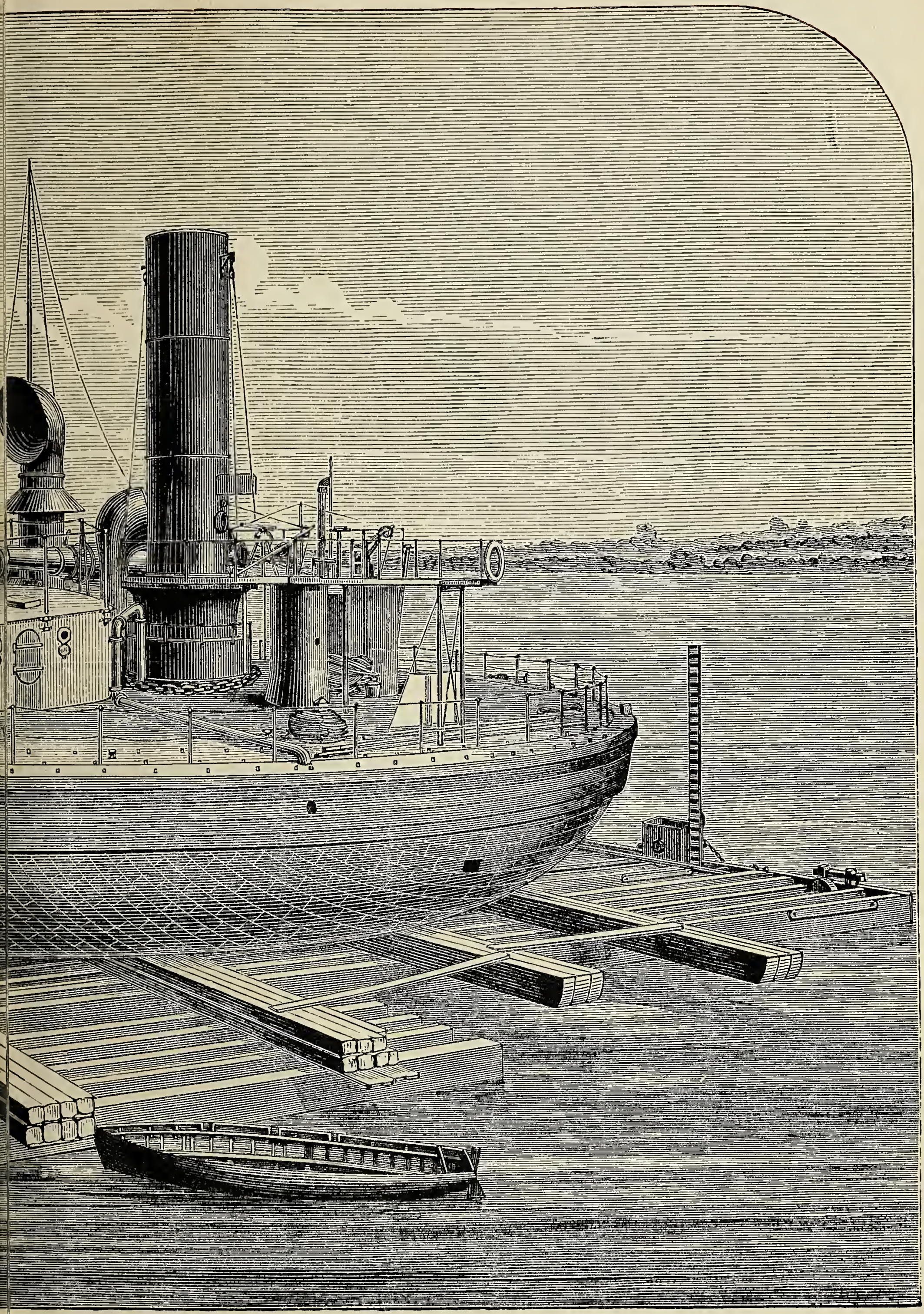


ING FLOATING DOCK.

THE NICOLAIEFF DEPOSITING FLOATING DOCK.

tubes will be effected solely in the direction of the vertical sections, or the buttock lines. The diagrams (see pages 240 to 242), give the principal sections and plans of the yacht. You will see that a large superstructure has been built upon the main body of the turbot-shape of the dimensions and of the form I have just mentioned. This superstructure is of the shape of an ordinary vessel, and because being of usual form, will no doubt gratify the eye of those who are not sufficiently educated to admire the uncovered sides of the lower turbot portion of the ship, which, however, are the very parts that have the greatest share in limiting the rolling at sea. Waves, from whatever point of the compass, developed either by the motion of the ship at very high speed, or by the capricious will of Nature, will ascend up the rounded sloping sides of the vessel, but finding there perfect freedom for their play, will have soon to subside, as the sloping deck is of a shape that does not admit of green seas remaining long upon it, unless in the form of a very thin sheet of water, quickly disappearing altogether. No additional buoyancy, therefore, is created alternatively at either side of the ship, and hence the rolling becomes a motion which, in the big waves, might follow the steepness of the swell, and, in small waves, actually reduces itself to nothing. Very often when on board a circular ironclad steaming in a gale, watching the behaviour of the boisterous seas about the rounded deck of the vessel, I was lost in admiration of the fruitless attempts made by the picturesque phosphorescent waves—illuminated brightly, on a dark night, from underneath by the deck lights—to produce any influence on the majestic steadiness of the ship. At that time, my deficiency in painting prevented me from the reproduction on canvass of my impressions. Here, before you, gentlemen, feeling my deficiency in English, I am again prevented from giving to you a better description of the phenomenon ; but to complete what I said regarding the behaviour of the seas about these vessels in heavy weather, I believe I cannot do better than to refer some of you, desirous of fuller information on that point, to the splendid articles which appeared in the *Times* newspaper from the pen of the eminent writer, Mr. Reed, late Chief Constructor of the Navy, who described several passages made by himself on board of these typical vessels, and whose system of widening and shortening ships had much to do with the origin of the idea of circular vessels in the mind of Admiral Popoff. The parts beyond the superstructure already referred to, represent to you the extent of the palace carried by the yacht.

"The turbot-like lower part of the vessel contains machinery, coals, and stores of all kinds. The steel superstructure rising over it contains accommodation for the crew forward, and for the officers aft, whilst the palace beyond it includes only the imperial apartments and the cabins for the suite.

"This turbot-like portion of the vessel is built of steel, with a double bottom, whose height is no less than three feet six inches in the centre. This double bottom is divided into forty watertight compartments, and extends throughout the flat portion of the bottom. At the sides it is superseded by the cells formed by running two vertical bulkheads right round the ship, and subdividing the distance between them and the outside skin into forty other compartments. These side cells, formed of continuous bulkheads, and covered by the plating of the rounded deck, present a very rigid, continuous, annular structure, which has its lower points tied together by the radial girders, forming the bracket framing of the bottom, and by the heavy beams of the rounded deck, also radial, at the top. Thus the turbot-like portion of the vessel is made amply strong enough to withstand those forces which might be experienced in the roughest seas, and the local strains, such as those produced by the powerful machinery with which the ship is provided—particular attention being paid to the structure of the stern, in order to distribute the strains on the brackets supporting the propelling shafts of the side screws.

"I need not go into the strength of the superstructure that rises above the turbot portion of the vessel, as it has been mainly designed to form a support for the palace and deck-houses beyond, in order to raise them so much above the level of the sea as to prevent anything but spray reaching those portions which are intended for the use of the imperial party.

"The palace, as will be seen from the diagrams, is not so wide as the steel superstructure, so that all around it on the deck a continuous gallery is formed, which is used for stowing anchors, mooring the vessel, hoisting up boats, steam launches, and a small steam yacht, carried on the davits, which are supported by bridges projecting radially outwards from that gallery.

"The roof of the palace is carried right over to the same width as the lower superstructure, thus forming an awning over the gallery, shading from sun or rain the lower story of the palace, and widening at the same time the promenade above. Inside the lower story forward, and away from the heat and smell of the engines and galleys, are the apartments for the emperor, and aft, those for the suite. Their number is not great, but their size is very much larger when compared with the cabins existing on board of any other ship. Accommodation of exceptional comfort had to be studied in this case. In the inside of the superstructure below here in the palace, the middle portion between the engine and boiler hatches is allotted to a passage across the vessel communicating with either end by means of two longitudinal passages, and also with the deck above. Such principal thoroughfare, by its convenience, marble pavements, electric lighting, &c., reminds one of the lofty staircases and spacious corridors in some palaces on land.

"Beyond the promenade on the awning deck rises a reception saloon, whose height is twelve feet, and therefore greater than has been reached on board any other ship. In its forward part will play a fountain, surrounded by a bed of

flowers. The whole decorative works of this saloon will remind us of the rooms of Louis XVI. at Fontainebleau, and the designs of this and other apartments were prepared by the well-known Scotch artist, Mr. W. Leiper. The drawing-room will be furnished in the Crimean-of the ship. Just in front of the funnels is the bridge, from which the ship will be governed, either by the steam steering gear acting upon her rudder, or by means of another gear designed for steering the vessel by means of her side screws.

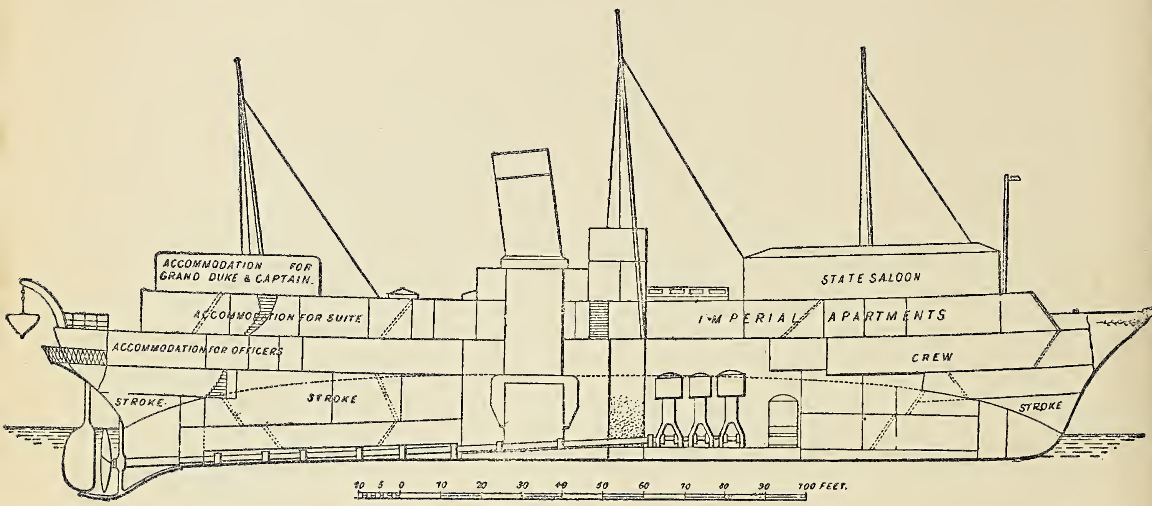


Fig. 185.

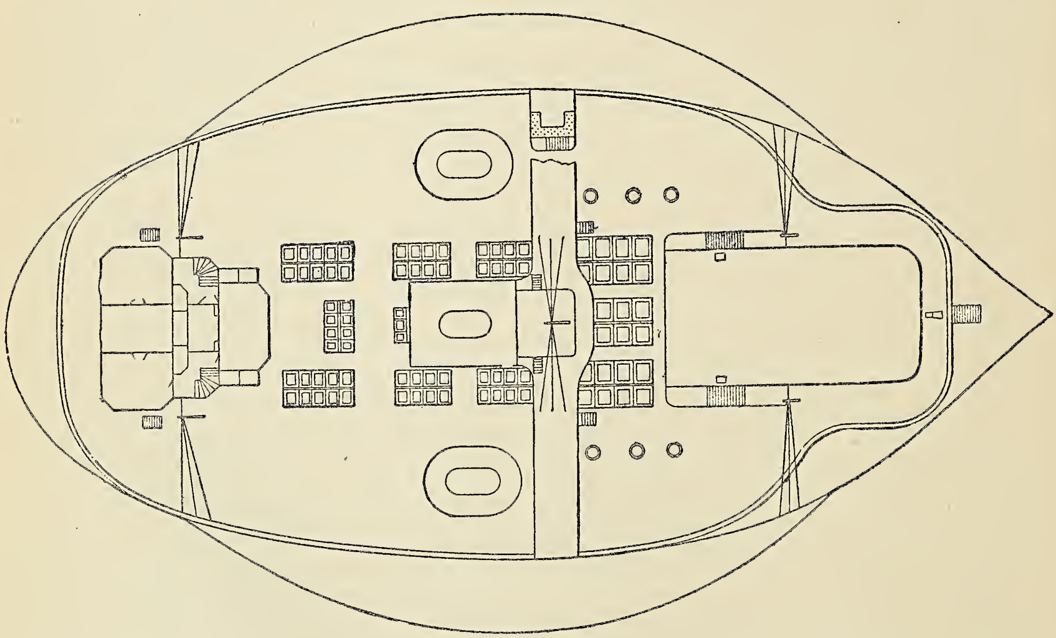


Fig. 186.

Tartar style, whilst other rooms will be of a simple kind of modern English, regard being made to obtain the greatest comfort.

"Behind the funnels on the same awning deck stands another deckhouse, including rooms for the Grand Duke Constantine and the captain

"It is scarcely possible to enumerate the improvements introduced in all their details. The system of distinguishing red, white, and green electric lights has been worked out under the guidance of His Imperial Highness the Grand Duke Constantine. The system of pumping out

the water-tight compartments is deserving of special notice, as does also the town-like system of water service, to which, I believe, for the first time on board ship, there are added loaded accumulators to produce pressure when the

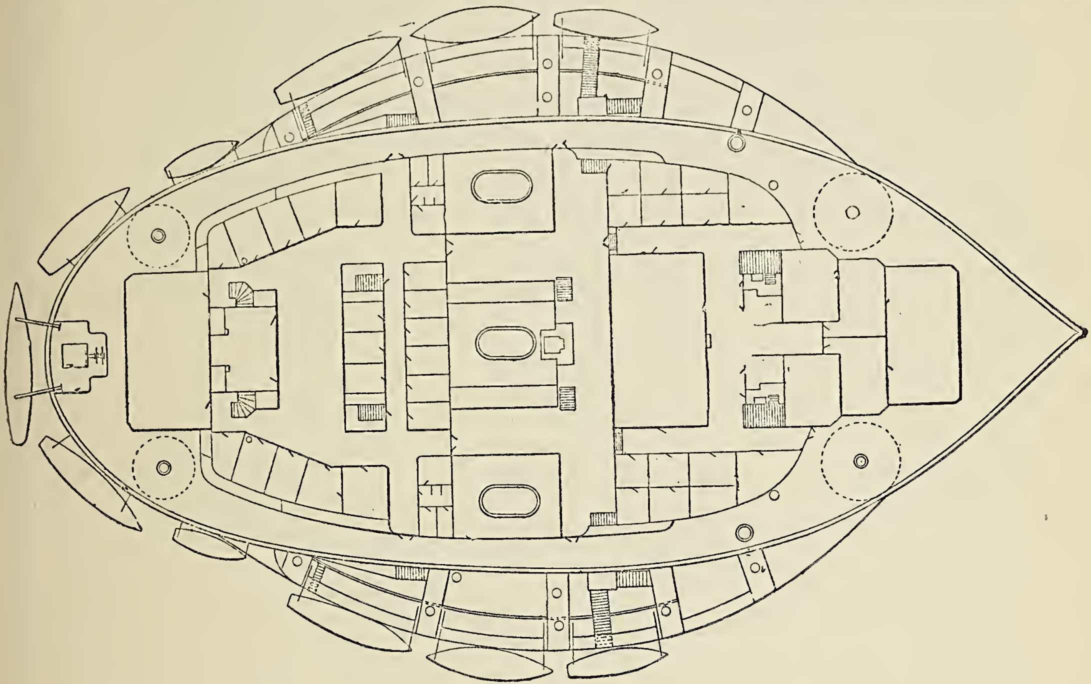


Fig. 187.

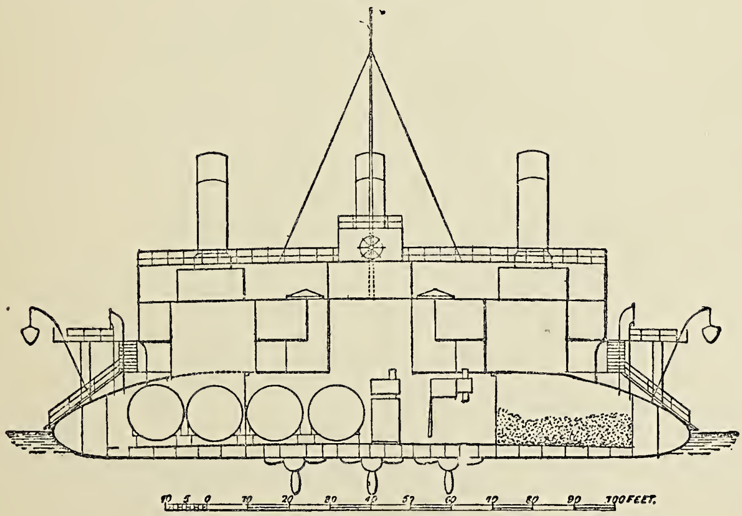


Fig. 188.

steam pumps are not at work. Machinery has been employed largely to supersede manual labour, and there are no fewer than twenty-three separate steam engines on board for different purposes.

"The propelling engines of the yacht, which have been designed by Mr. A. D. Bryce, are of a construction decidedly novel, and have been erected in a somewhat novel manner. Their foundation, which is of steel, forms part of the framing of the double bottom, as is also the case, on a smaller scale, in the circular vessels. We hope that, with many other important improvements introduced in these engines, we shall obtain a greater amount of indicated horse

power, as compared with their weight, than with any other marine engine yet constructed (torpedo boats excepted), and that they will satisfactorily answer the problem entrusted by Admiral Popoff to Mr. Bryce.

"The arrangement of propellers forms another very important peculiarity in the design of this vessel.

"The efficiency of submerged screws beneath the ship's bottom has been sufficiently tested

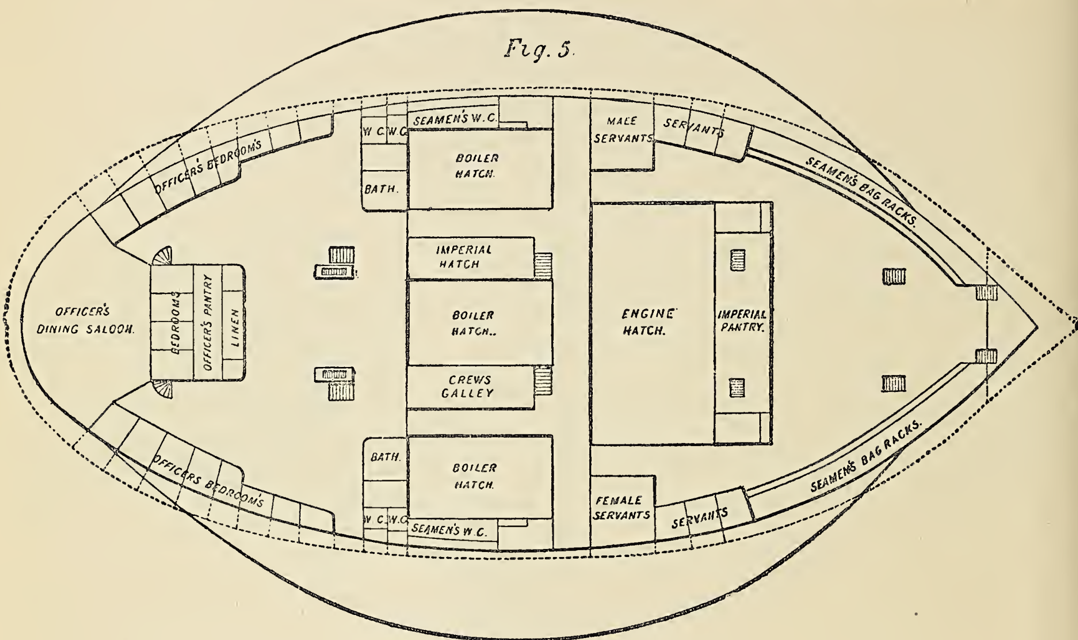


Fig. 189.

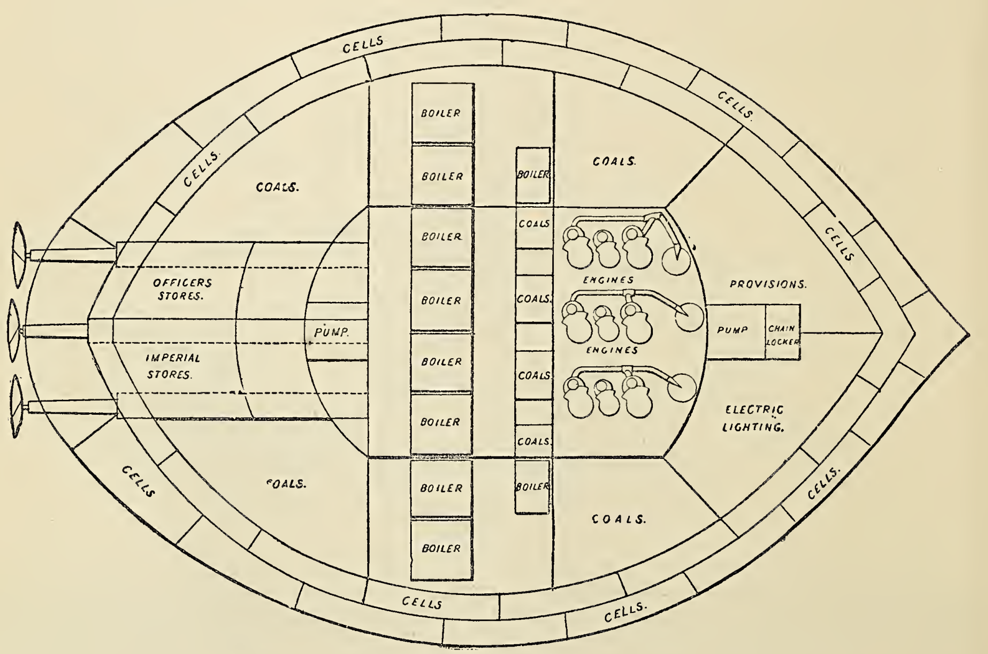


Fig. 190.

previously by Admiral Popoff, but so much as having two-thirds of their diameter entirely below the outline of the vessel is a decided novelty, which, as was expected, will greatly add to their efficiency, as has been corroborated by the recent experiments conducted to that effect, on Loch Lomond, with a steel model of the yacht one tenth the ship's size. There are three screw propellers of 16 feet in diameter, spaced 18 feet 3 inches apart—the centre one being in the line of keel, and each of them worked by an independent engine capable of exerting an indicated horse power of 3,500.

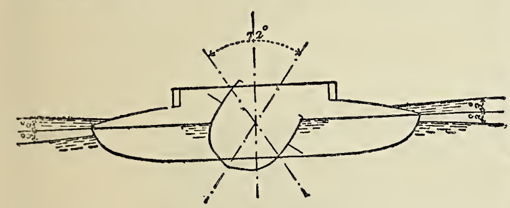


Fig. 191.

"Now, having described to you the vessel, I shall beg you to turn your attention to the second portion of the paper, namely, to 'Vessels of her Type considered as Means of International Communication.'

"During the last few years the means for such communication have reached a high state of development, and the great improvements introduced are already increasing and facilitating commercial, scientific, and friendly intercourse among the nations, and are tending to bring more and more the light of civilisation to bear upon those portions of the human race whose isolation from other parts of the world was the only cause of their primitive state.

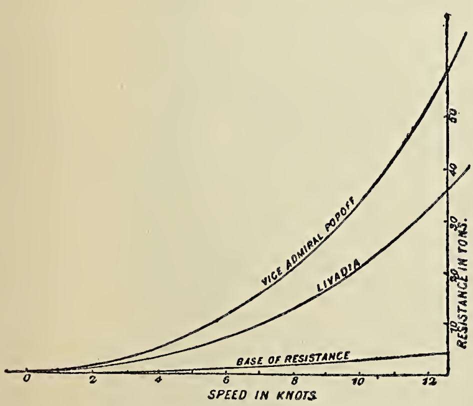


Fig. 192.

"Already one immense line of railways crossing the Continent of Europe, or that of the United States of America, from end to end, competes with another line of similar extent, in affording comfort to passengers and in saving so many hours in the journey. Every year the number of railway companies continuing to disregard the comfort of travellers is decreased, and with the sleeping and dining cars introduced on nearly all lines of importance, travelling is done with such ease that the journey becomes no longer a source of trouble but the reverse.

"However important in relation to the economical development of separate states are the means of communication just spoken of, there are others which are scarcely of lesser importance, especially so in relation to commerce and civilisation—and one of these is the steam navigation. I specified it the steam navigation, because only the application of steam insured the possibility of establishing an uninterrupted connexion of all parts of the world. So great is the demand for the means of emigration from the Old World to the New, often in very large masses of people, and the demand for the means of travelling, that already, at least one steamer a day is despatched from the shores of Europe to America, and, no doubt, the same will be the case with our communications with the other parts of the world, such as Australia, as soon as greater knowledge has been obtained of the climate and natural wealth of this new continent. Thanks to the continuous success in shipbuilding —success for which we are greatly indebted to the Clyde shipbuilders—already the distance to America has been decreased to a week's journey, and to Australia, to a passage of one month. I know that Mr. Pearce (of Elder and Co.) is not satisfied with these results, though they were brought about partly through his own enterprise, and is prepared to surpass them, being ready to construct a fleet of steamers that will run the distance from Liverpool to New York in less than six days, and will establish the 'Express' Ocean Service.

"Thus we see that the great strides in steam navigation have given us nearly as good means of rapid locomotion at sea as have been reached by railways on land, but so much cannot be said in relation to comfort. Notwithstanding an ardent desire on the part of shipowners to turn their steamers into floating hotels, as convenient for living and as luxurious in their internal arrangements as are hotels on shore, people, with very few exceptions, regard a voyage by sea with mistrust, and even with dread at the thought of that helplessness to which are subjected both men and women, when the calm of the sea, so pleasant for travellers, changes into a heavy boisterous swell whose end no one can predict. No care in improving the internal accommodation, however luxurious—and, in most cases, more luxurious than the interior of the first-class railway carriage, at whatever expense to the owner of the ship the luxury is obtained—can alleviate these feelings of the masses of passengers."

Captain Goulaeff then goes on to express his belief that vessels of the "Livadia" type will prevent sea-sickness, and also states that interoceanic communication would be greatly improved in respect to vessels of this class.

The vessel was safely launched. We remark

safely, for owing to the political disturbances in Russia, which, as we have already noticed, culminated in the assassination of the Czar in March, 1881, every precaution had to be taken against plots which were said to exist to destroy the vessel while in course of construction. Her trial trips took place early in October, and the following account of them we quote from *Engineering*.

"The official speed trials of the Czar of

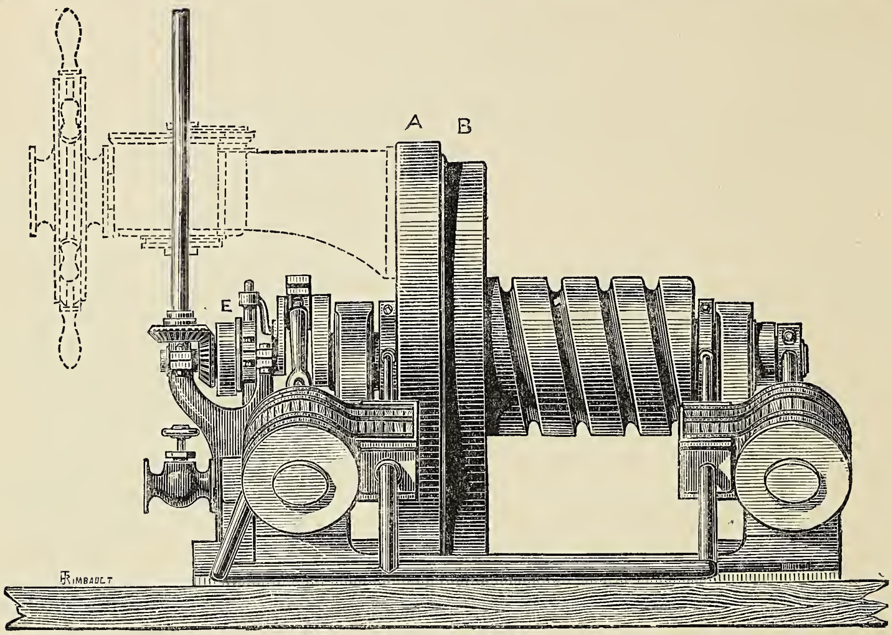


Fig. 193.

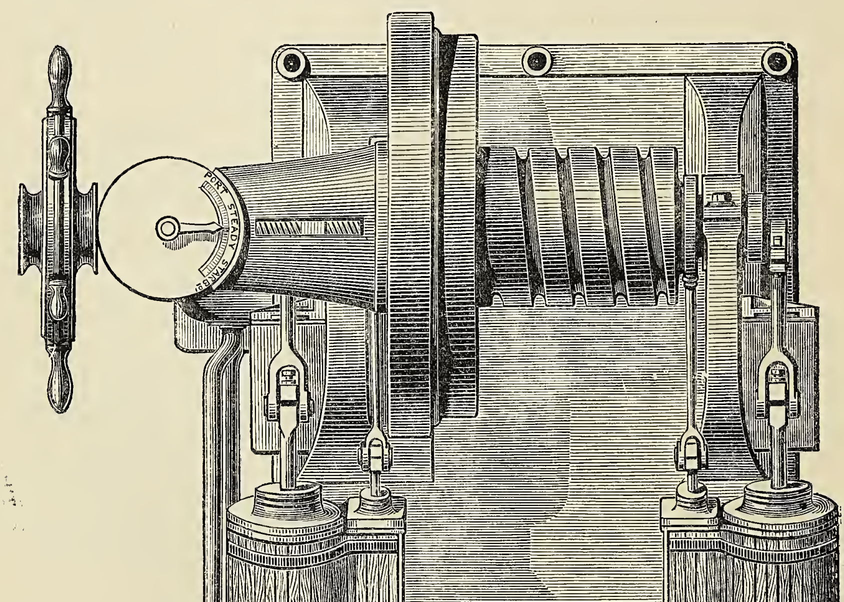


Fig. 194.

Russia's yacht 'Livadia,' which have been awaited with much interest, took place on the Clyde on Friday (October 8th), and Saturday last. On Friday the six hours' run took place, and on Saturday the measured mile trials. On both days the speed considerably exceeded that guaranteed by the builders, a result which is not surprising, and one that we foreshadowed when the vessel was still in course of construction. In the run from the Tail of the Bank to the South of Arran on Friday, the vessel was timed between the Clock Light and Cumbrae Light with a speed of 15 knots, and the speed by the log was 15½ knots. On Saturday there were

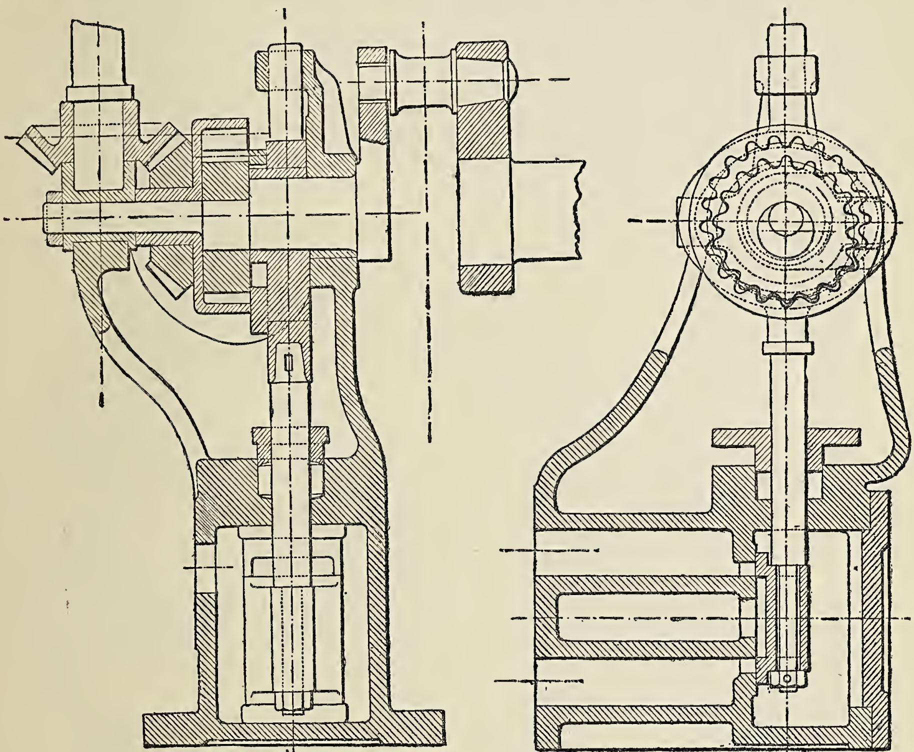


Fig. 195.

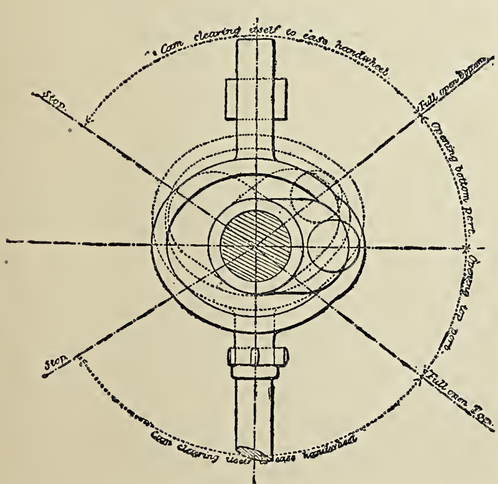


Fig. 196.

six full-power runs over the measured mile, and the following are the results reported :—

	knots.
First run.	16
Second ,, ...	15·652
Third ,, ...	16
Fourth ,, ...	15·755
Fifth ,, ...	16
Sixth ,, ...	15·755

The mean indicated horse power is given as 12,383 horse power and the mean speed as 15·864 knots.

"It will be remembered that the vessel is 250 feet long and 153 feet wide, and that the estimated speed was 14 knots, the estimated horse power, 10,500, and the estimated displacement 3,900 tons. All three elements have, we understand, been considerably exceeded. The engines developed nearly 2,000 horse power beyond the contract guarantee, and the speed is nearly two knots in excess. How much the displacement exceeds the estimate has not yet transpired, but it is clear that without the 2,000

extra horse power the speed would have been above 14 knots, notwithstanding the increased displacement. So far then it must be conceded even by those who have scoffed at the 'Livadia' that the estimates made of her speed, have been more than justified, and that an acknowledgment of the same is due to Dr. Tideman on whose model experiments the estimates were based, and also to the builders, Messrs. John Elder and Co., Admiral Popoff, and the Russian officers who have staked so much on those estimates.

"In view of the extreme novelty of this vessel it is much to be regretted that a series of progressive trials were not made on her for scientific purposes. It is one thing to make the requisite full speed trials on the measured mile and on the six hours' run to satisfy the terms of a contract; it is quite another thing to make a really scientific series of trials at different speeds so as to record the variations in the vessel's resistance as the speed varies. The latter should be done for all vessels, and especially for vessels of novel type. It may be that the fear of Nihilist plots to blow up the ship (already alluded to), might have caused the builders to hasten the transfer of her to her owners, and might have induced the Russian authorities to press for her delivery. This is a reasonable and intelligible explanation, and we can scarcely think that without some pressure of the kind Messrs. Elder and Co., would have missed so rare an opportunity of gaining what could not fail to have been some remarkable data on the resistance of vessels. As was to be expected, the vessel carried a very marked wave round her bow, and left the water much disturbed by waves behind her. The engines worked satisfactorily throughout, and we have not heard any rumours of heated bearings, which were of Parsons's white brass. The propellers were of Parsons's manganese bronze, and the great strength of this material, which enables the blades to be made comparatively thin, and its smoothness of surface, doubtless tended in some degree towards the favourable results achieved. It would be interesting how far the slope of the propeller shafts from the horizontal line affected the trim of the ship during the trials. The chief interest now will be centred in her behaviour in the Bay of Biscay, as to all appearances she may expect some heavy weather, and it is almost as great a risk to speculate on her seaworthy qualities as her speed."

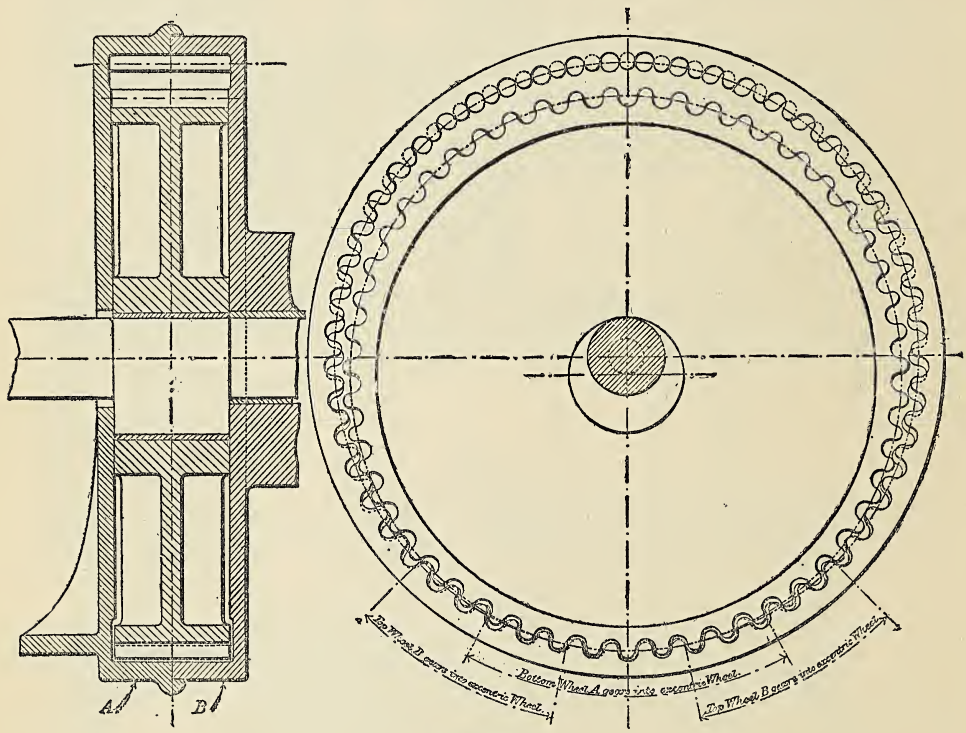


Fig. 197.

The result of her voyage across the Bay of Biscay we have already stated, as ending in her harbouring for the winter in Ferrol. Consequently, we are without information in every respect as to her sea-going qualities, and how she behaved in a storm.

In the preceding account of the "Livadia" it has been stated that she has on board no less than 23 steam-engines. Here it may be explained that on all large steam vessels of the present day, nearly every kind of heavy work

is done by steam in place of manual labour. Thus in merchant vessels all the goods, &c., are put on board by means of steam-cranes or other contrivances, and similarly the vessels are unladen by the same means. The anchors are raised by steam, and numerous other operations are performed by the same means. Among these is the work of steering the vessel. In calm weather, the steering of a steam or sailing vessel of heavy tonnage is laborious work, even for a couple of men. But on the open ocean in

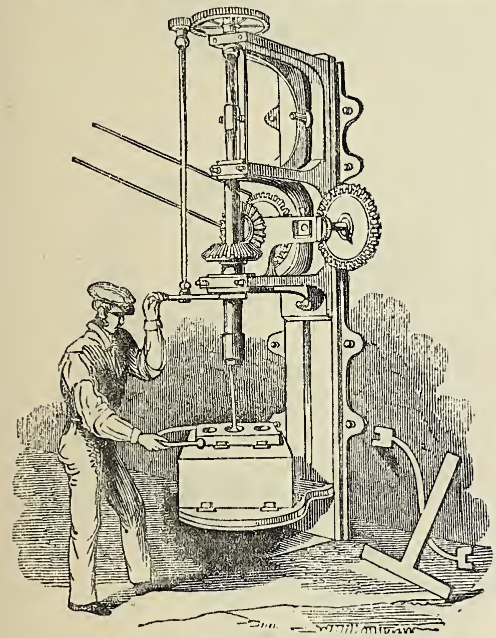


Fig. 198.—Boring Machine.

rough weather the operation is a dangerous one. Steam has, therefore, been called in to aid the mariner, and among many inventions of the kind, we may instance the following, for the description and illustrations of which we are indebted to *Engineering*, but slightly altered to suit the nature of this work :—

"A very simple arrangement of steam steering gear has been patented and constructed by Mr. James Nelson, of Gateshead-on-Tyne. In describing the gear, it may be considered as consisting of two parts, namely, first, the engines and their connexions, by which the necessary power is exerted on the chains leading to the tiller; and, secondly, the hand gear and control motion by which the engines are started and stopped as required.

"In the arrangement of the gear, shown by our engravings Figs. 193 and 194, there is a pair of engines having cylinders 6 inches in diameter with 8 inch stroke, these engines lying almost horizontally, and the connecting rods being coupled to cranks placed at right angles to each other, and situated at opposite ends of the shaft which carries the chain drum. The chain drum is not fixed to the shaft, but is capable of revolving on it, motion being communicated to it as follows : Forged on the shaft, and just clear of one end of the chain drum, is an eccentric, this eccentric carrying a spur wheel, as shown in the detail views, Fig. 197. The spur wheel is of such width that it is capable of engaging two internally geared wheels, as shown in the section Fig. 197, one of these wheels being cast in one with the chain drum, while the other is fixed to the bedplate, and does not move. There are fifty teeth in the fixed wheel and fifty-one in the wheel on the chain drum, the result being that as the wheel carried by the eccentric is rolled round on the pair of internal wheels, the barrel wheel is shifted round one tooth at each revolution of the crankshaft. The arrangement is more compact than a train of spur wheels, and being all boxed in there is no chance of things getting into the teeth. The friction is, of course, much greater than in ordinary spur gearing, but it is probably smaller than with worm gear.

"The engines are fitted with piston valves, and the reversal is effected by transposing the steam and exhaust connexions. This transposition is effected by an ordinary D-slide arranged as shown in Fig. 195. As will be seen from the latter view, this valve covers three ports, of which the central one communicates with the exhaust pipe, while the two others respectively lead to the inner and outer sides of the piston valves of the engines. Thus according to whether the D-slide is raised or lowered, the piston valves receive steam in their inner or outer sides, and the direction of movement of the engines is thus controlled.

"Referring again to Fig. 195, it will be seen that the spindle of the D-valve just mentioned has formed on it a ring which encircles a cam mounted loosely on a short shaft which is driven by an extension of one of the engine crankpins, as shown in Fig. 195. The forms of this cam and ring are shown by Fig. 196, from which it will be seen that when the cam is in the position shown by the full lines, it fits the ring closely, and thus a small movement of it will raise or lower the valve promptly according to the direction of the motion. As soon, however, as the cam has caused the valve to uncover the upper or lower port fully, it comes into contact with a portion of the ring so shaped that a further movement of the cam causes no further movement of the valve, but merely keeps the latter in the position in which it has been placed. In Fig. 196 the effects of the cam in its different arcs of movement are clearly shown.

"We have said that the cam just mentioned is loose on the shaft which carries it, but it is connected to an externally geared wheel, which is inclosed within an internally geared wheel, and this wheel is, in its turn, connected by bevel gear to the steering wheel under the command of the steersman. The externally geared wheel just referred to is mounted on an eccentric formed on the short-shaft which carries the cam and internally geared wheel, the whole arrangement being clearly shown by Fig. 196. The effect of this arrangement is, that when the

internally geared wheel is turned by the steersman, it carries round with it the wheel mounted on the eccentric part of the shaft, and also the cam, the result being that the D-valve is shifted, and the engines started either forward or backward, according to the direction in which the cam is moved. But directly the engines are put in motion the externally geared wheel, which we have mentioned as connected to the valve cam, is carried round by the eccentric on which it is mounted, and gearing into the internally geared wheel which incloses it, it gradually shifts back the cam, and eventually brings the D-valve into its central or neutral position, thus stopping the engine. The number of revolutions made by the engines before this effect is produced,

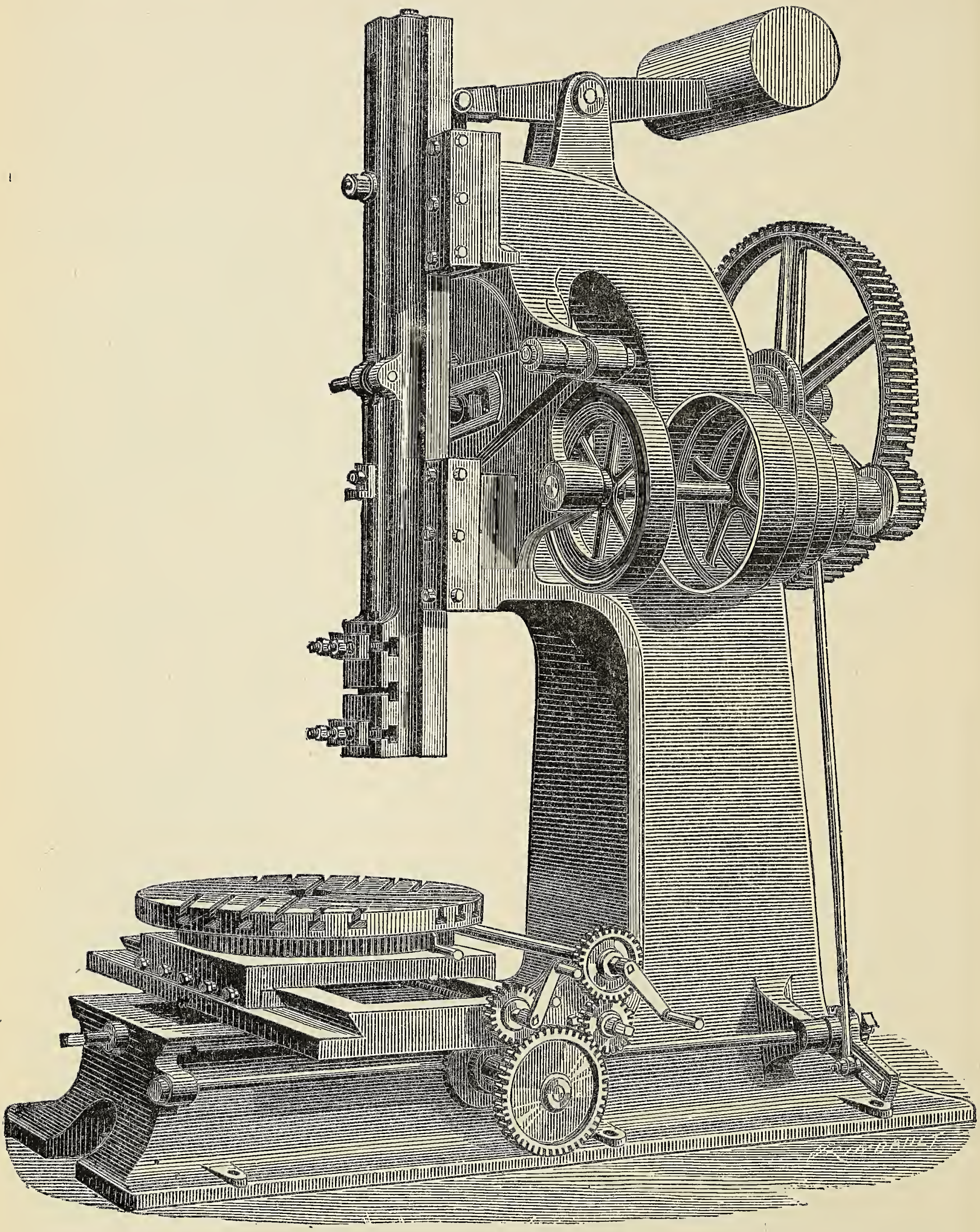
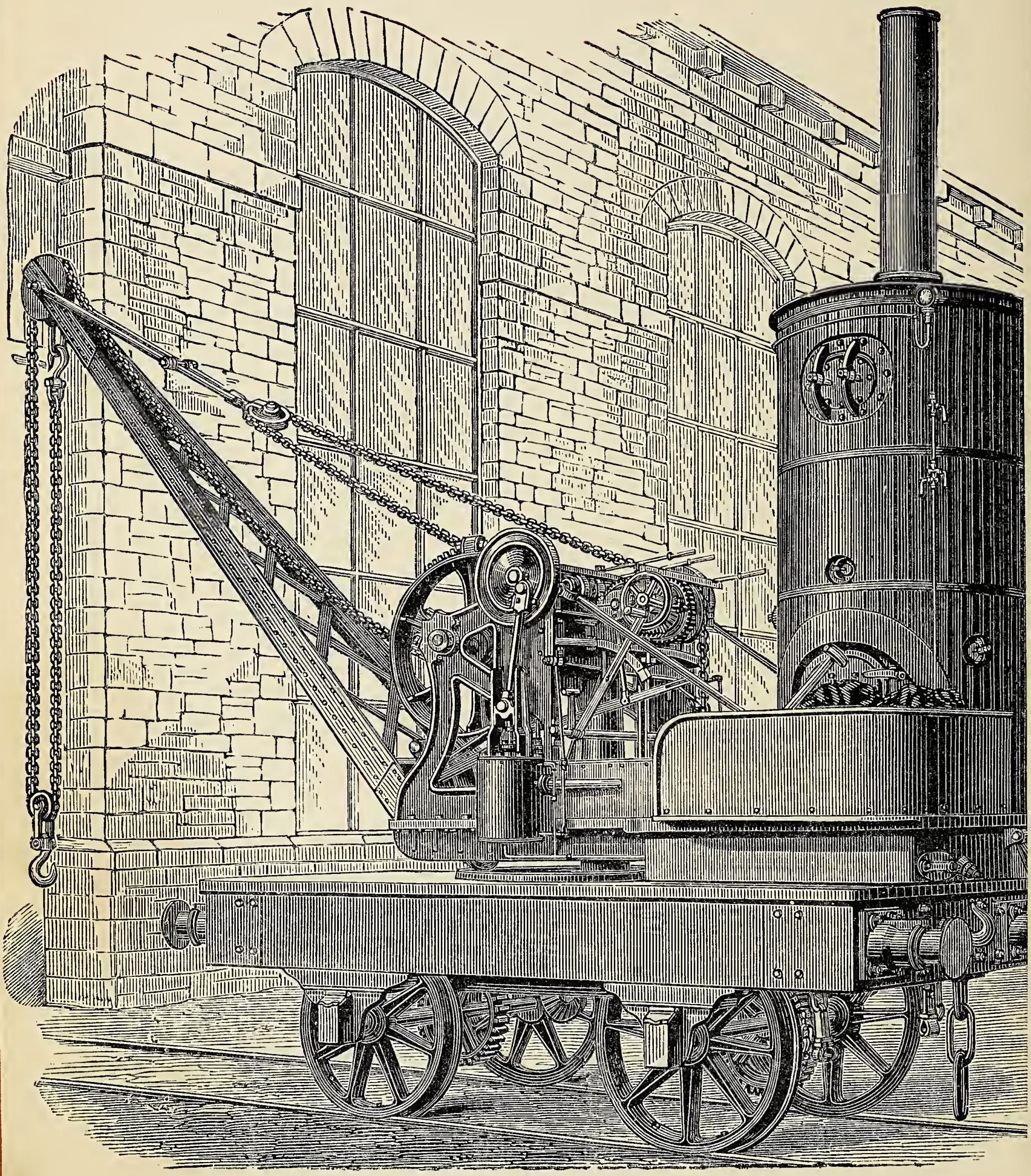


Fig. 199.—Asquith's Slotting Machine.



SMITH'S TRAVELLING CRANE.

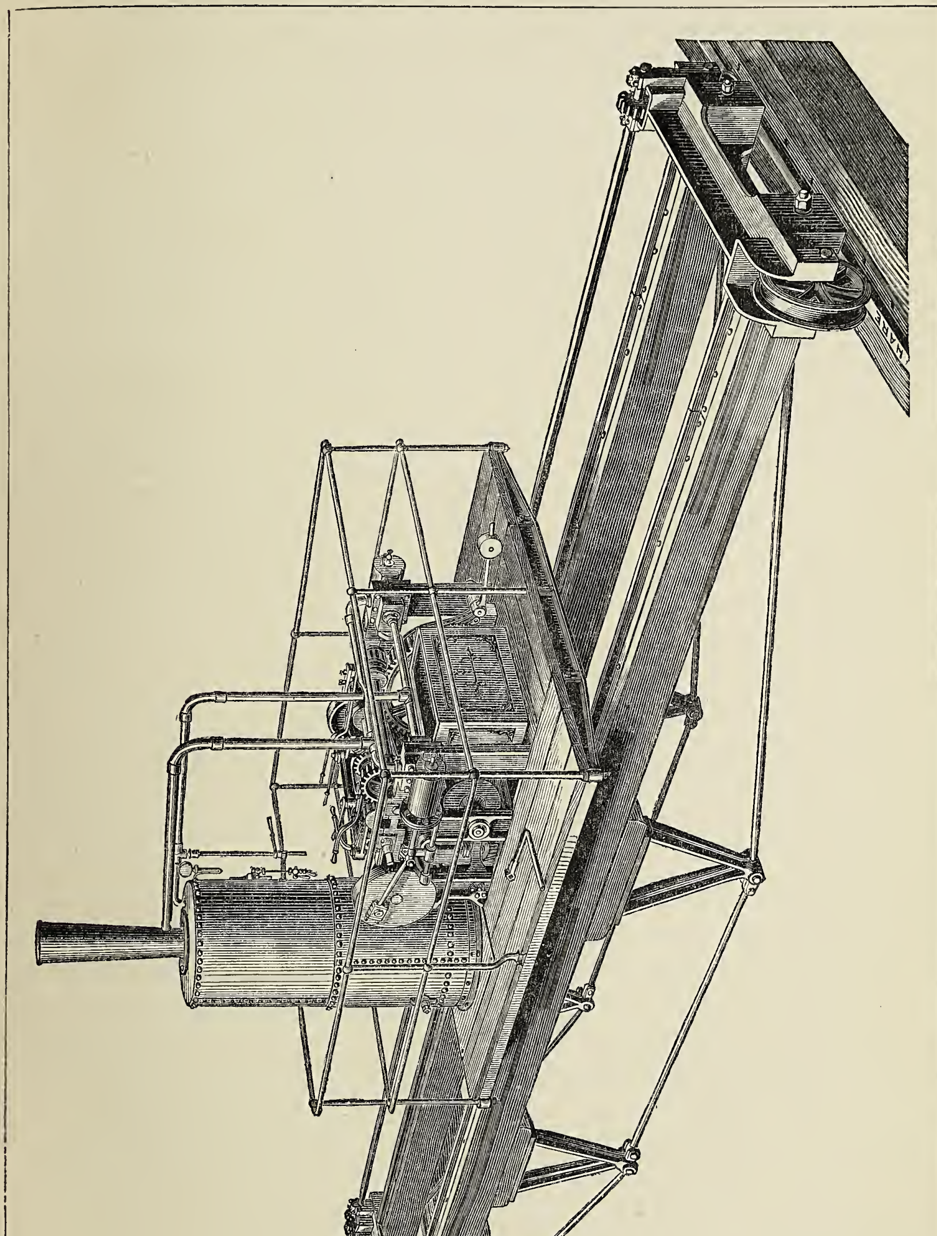


Fig. 200.—Overhead Steam Travelling Crane.

depends, of course, upon the arc through which the cam has to be shifted back, and hence the number of revolutions made by the engine—or, in other words, the amount of movement imparted to the rudder, is exactly proportional to the extent of movement of the steering wheel under the control of the steersman.

"This steering wheel is of the conventional pattern, and is placed wherever may be most convenient. The dotted lines in Fig. 193 show how it can be mounted on the steam steering gear if desired. The gearing operated by the wheel is so proportioned that about twelve turns of the wheel are required to put the helm over from hard-a-port to hard-a-starboard, this proportion being adopted so that the manipulation of the wheel may be about the same as that of an ordinary steering wheel. There is a strong screw on the shaft which carries the handwheel, this screw being fitted with a nut moving on a slotted groove, so that it acts as a stop and prevents the steersman from turning the wheel too far in either direction. There is also a dial with index conveniently arranged close to the steering wheel, and showing the position of the rudder.

"As will be seen from our illustrations, the whole arrangement of the steering gear we have been describing, is very neatly worked out, and we hear that the gear has given very satisfactory results in practice."

Into the minutiæ of iron or steel ship-building, we cannot enter, for to do so would involve a description of scores of patents and their illustrations, which would exceed the space that could be afforded in this work. The detailed description of wood-ship-building, already given supplies a general idea of the subject. In a timber-built ship, the keel, the ribs, the stem, the sternpost, and the planking, constitute the principal part of the hull, and are all made of stout timber; but in an iron or steel vessel, the whole of these parts are made of that metal; and it is quite surprising to see the lightness and apparent slightness of the whole structure, as compared with the ponderous timber-built ship.

The keel of an iron vessel is formed of several pieces, bolted end to end in a very secure manner: it is by no means large in bulk, for a keel six inches deep by three in width will serve for a vessel of a thousand tons burden. There is a range of holes passing through the keel from side to side, intended for the reception of rivets for fastening the various parts of the hull together. The ribs, instead of being vast beams, are merely iron bars, bent into the required curve, from the keel upwards. A bar of iron three inches square is sufficient to form the rib of a very large vessel; and even this is greatly reduced in weight by the hollowing out and removal of a good deal of the metal at one edge. The metal is brought to the exact form in a rolling-mill, where it passes between rollers grooved so as to give it the required section. Holes are bored in various places for the insertion of rivets; and the bars of iron, when prepared for use, are heated in a furnace, and bent round to the curvature of the hull. Each curved piece forms a rib, and is riveted very securely to the keel, the ribs being placed at a distance of about eighteen inches apart.

The outer surface, or what may be termed planking, of the vessel, instead of being formed of oak planks, is made of sheet-iron, rolled to a proper degree of thickness into large sheets. These sheets are cut up by means of a powerful kind of shears or cutting instrument worked by steam, and have then a series of rivet-holes punched in them round the edges; they are bent into a curved form, and finally fastened to the ribs by means of numerous rivets. When the skeleton of the vessel is thus put together, the distinguishing points of difference between it and a timber-built ship are nearly at an end, for the interior fittings are much the same in both, and so also are the arrangements connected with the steam-engine and machinery.

The ship-yard for iron and steel vessel construction greatly differs from the wooden ship-building yards already described in page 223.

As already explained, it is considered that the business of the iron manufacturer ceases when he has brought the iron to the state of pigs, if for cast-iron; or to the state of bars or sheets, if for wrought-iron. Beyond these points, the practical application of iron belongs to one or other of the numerous departments into which metallurgy is divided. The shipbuilder, the engineer, the machinist, the millwright, the wire-drawer, the steel-maker, the cutler, the needlemaker—all take up the operations at the point where the iron-maker leaves them. Some of these ulterior processes will come under our notice subsequently; but it may be well here to glance at a few mechanical processes which the iron undergoes to prepare it for more minute subdivision and application—such as "cutting," "boring," "drilling," "planing," &c.; operations which form an important part of the labours at the great engineering establishments, such as that which has become immortalized in connexion with the name of Watt.

When sheet-iron is to be used for boilers or other purposes, it requires first to be cut into pieces of definite shape and size, and then to have holes bored for the reception of the rivets by which the several pieces are fastened together. The cutting is effected by instruments of different kinds, according to the thickness of the sheets; but the instrument is generally a kind of enormous shears, worked by a steam-engine. It is from sheets of iron, cut and punched, that the huge boilers for steam-engines and steam-vessels are made: the sheets of which they are formed are fastened together mainly by means of rivets driven into holes in the doubled edges. There is perhaps scarcely any other department of manufacture in which the noise is so deafening as that resulting from this process, especially where, as in some cases, it is carried on under a roofed building. At a subsequent page we shall have to further enter into the subject.

Another process is that of "boring." After a cylinder or a barrel has been cast in sand, in the way before described, the internal surface,

although presenting a general cylindrical form, is too rough for the nice adjustments required in engineering; and it has consequently to be rendered smooth by the action of a cutting instrument. The term "boring," applied to such a process, is perhaps not quite a fitting one; since we should understand by it rather the making of a hole than the mere perfecting of it when made. Some of the large cylinders for steam-engines, five or six feet in diameter, require the use of boring-machines of immense magnitude and power. Each such machine consists of a long bar or axis, which is made to pass through the cylinder, and from which project arms, having cutting points of steel at their extremities: these points come in contact with the internal surface of the cylinder; and by being made to rotate rapidly they scrape off minute fragments of iron: this being continued from end to end, by the advance either of the machine or of the cylinder, the whole inner surface becomes scraped smooth. In the large machines the boring-rod generally works horizontally; but in smaller machines, for finishing holes in iron pieces of small size, it is vertical (Fig. 198). This smaller kind of boring-machine does not differ very much in principle from the "drilling-machine." In it a sharp point of well-tempered steel, fixed to the bottom of a vertical rod, is made to rotate with such velocity as to drill a hole in any piece of metal which may be placed beneath. If the metal be a piece of sheet-iron, holes in it are usually made by punching; if it be plate-iron of greater thickness, the holes are made by drilling; where it is a thick piece of cast-iron, the holes are generally made in the casting, and afterwards completed by the boring-machine.

A machine of great power and accuracy is used for planing the surface of metal, by which a truthfulness of level is obtained which could not result from any other process: indeed, much of the beauty of modern mechanism is due to the use of the planing machine. The flat piece of iron which is to be planed, whether it be a large plate or a long bar, is laid down perfectly horizontal on a bench, where the planing-machine may act upon it. This machine has a sharp steel cutter fixed at the lower part, the edge of which is brought to bear upon the surface of the iron; the whole surface is scraped successively by this edge, so as to give perfect regularity to every part. This machine is the same, in respect to its principle of action, as the boring-machine, since the effect is in both produced by this scraping action; the difference observable being due to the different kind of surface operated upon.

"Turning" is another process whereby the surface of iron is brought to the requisite degree of smoothness. It is effected nearly in the same way as wood-turning; the article to be turned being fixed horizontally in a lathe, and a cutting tool being made to act upon every part of the surface in succession. In wood-turning, however, the fragments are taken off in the shape of shavings and chippings; whereas in metal-turning they are much finer.

Another arrangement of considerably use in the machine shop is that used for making slots in iron shafts, &c. We are indebted to *Engineering* for the representation and the following description of a slotting machine of improved construction:—

"In the engraving (Fig. 199, p. 248), is an illustration of a large slotting machine for heavy work, constructed by Mr. William Asquith, of the Highwell Road Works, Halifax. The ram has 20 inches stroke, and has a slow-cutting and quick-return motion, these motions being given by a link and sliding block as shown, and the parts being so proportioned that the connecting-rod from the block to the ram is never more than 5 degrees from the vertical line. The ram is balanced so that the return stroke is made as easily as the down stroke, and wear and tear of the belt is thus saved. The machine will take in work 6 feet in diameter, and the table and cross slides are self-acting in the circular, transverse, and longitudinal motions, and have a variable feed. The table and slides are so arranged that the workman can control either or all of the motions from either side of the machine, thus facilitating the adjustment of work. The ram is adjustable by a worm wheel and screw at the centre of the ram, and in designing the machine great care has been taken to secure that handiness which is so essential to prevent loss of time in the working of tools generally. The weight of the machine we illustrate is 11 tons, and it is altogether of a very neat and substantial pattern."

In large iron ship-yards, and especially where the boilers and engines are also made, it is frequently necessary to move heavy masses, such as girders, boilers, cylinders, and many other heavy articles from one place to another. This is done by means of overhead steam travelling cranes, one of which, constructed by Messrs. Appleby, of London, is represented in Fig. 200. The engines and boiler, as will be seen in the cut, are supported on a railway at either end, raised at any desired height above the ground, and the load suspended beneath them can be moved in two directions, namely, at right angles to each other, the travelling and hoisting motions being all carried on by steam. Thus a boiler, or other heavy articles, can easily be transported from one end or side of the shop to the other, at little cost, and yet at the saving of an immense amount of time and human labour. The same plan is often used in bridge-building, and for a host of other purposes where similar objects have to be obtained in shifting heavy bodies.

For the present we must quit further description of the process of iron-shipbuilding, reserving the question of the motive power to a subsequent article. But here we may notice the two chief modes of propulsion that have been adopted for driving both wooden and iron, or steel vessels through the water.

At one time, the paddle-wheel was the only mode employed for driving steam-vessels. It is unnecessary for us to enter into any description of the appearance of paddle-wheel steamers, as they must be familiar to every reader of the work. As a matter of historical notice,

however, we introduce a representation of one which, being at the time of its construction one of the largest of its kind, was a source of much interest. We refer to the "British Queen," the remembrance of which is now nearly gone out of mind. (See Fig. 201).

The paddle-wheel, however, is gradually becoming a thing of the past, and is now almost entirely employed only for passenger traffic on rivers, and in the vessels used for crossing the English Channel, nearly all large ocean vessels being driven by the screw. The early history of the screw propeller is involved in much obscurity. The so-called "Archimedean Screw" was patented in 1838, by Mr. Pettit Smith. There are several other persons—some in America and some in England—that lay claim to the invention; but the basis of the machinery employed in screw-vessels is that devised by Mr. Smith, whose patents were purchased, in 1839, by a body of gentlemen, who were incorporated as the "Ship-Propeller Company," by an act of parliament passed on the 29th of July, in that year. Their first vessel was the "Great Britain," which commenced her career on the 26th of July, 1845. The directors of the company had subjected a small vessel, previously built, to many experiments, for the purpose of deciding upon the best form of the ship and arrangement of the screw; and, when the "Great Britain" was completed, she was much admired. There were no unsightly paddle-boxes at her side, covering the paddle-wheels, the action of which has been described as being, "in some measure, that of a pinion in the rack:" whilst "the motion of the screw may be compared with that of a screw in a nut." This screw is formed of a central iron axis, around which radial arms, or blades, are twisted; it is fixed at the stern, parallel with the keel; and being under water, is, of course, out of sight. There is nothing, therefore, to interfere with the graceful curve of the vessel; and the "Great Britain" was considered one of the most beautiful ships ever seen. She was the largest vessel that had been launched up to that time.

As to enter into any description of the various forms of screw-propeller that have been invented, it is simply necessary to say that their name is legion. The pitch, &c., are varied often, according to the ideas of the ship-engineer, or on various theoretical grounds. It will be more interesting, therefore, to the practical man, to reproduce the opinions of eminent authorities on the general subject. This we shall do in reference both to the single and twin screw modes of propulsion, the latter having of late become in high favour in certain quarters, for various reasons, that will be afterwards given. We are indebted to *Engineering* for the following observations:—

"The question of screw propulsion has been so long mixed up intimately with that of the resistance of ships, that it is not always easy to keep them so distinct from each other as is desirable for the sake of clearness. We refer, of course, in saying this, to the general and popular ideas on the subject. Men like Professor Rankine and Mr. Froude have long kept the line of demarcation between the two subjects distinct enough in their scientific investigations; but in practice, whenever we come to deal with the matter from the point of view of steamship trials, whether on the measured mile or on ocean voyages, we get the two things mixed up in such a way as to make it very difficult to draw a sound conclusion either on one subject or the other.

"We believe this is the main cause why the vast array of statistics derived from the steam trials made from year to year with the ships of the Royal Navy, and carefully recorded in the Department of the Chief Constructor of the Navy, have been of so little use in throwing light upon either screw propulsion or the resistance of ships.

"There can be little doubt that this state of things will soon come to an end, and that steam trials in the future will be conducted on a far more rational and intelligible system than heretofore. The objects aimed at will be higher, and more worthy of the vast expense that steam trials always entail; they will, let us hope, be directed to the elucidation of scientific knowledge without impairing, but rather greatly augmenting their usefulness for purposes of practical comparison.

"There can be no doubt that practically the Admiralty steam trials have been of great service to the designers of war-ships, because, knowing the forms of the lines of the different vessels, they could generally "thumb out" a set of constants for a new ship from those that had gone before her, and make a fair approximation to the speed. We can easily imagine, however, the sense of humiliation that would be felt by a designer having a scientific order of mind—and the Admiralty is fortunate in the possession of many such—in going through a process of this kind. The wonder is that some one from within the department has not broken down the old system of trials years ago; but perhaps it is a still greater wonder that more advance has not been made in the direction indicated by Mr. W. Denny, of Dumbarton, a few years ago in the paper read by him before the Mechanical Section of the British Association at Bristol, on 'Progressive Trials,' and especially since Mr. Froude showed, in 1876, before the Institution of Naval Architects, what a splendid harvest of scientific knowledge was to be reaped from the data supplied by such trials.

"Mr. Froude's words on the subject are as eloquent as they are instructive. 'No doubt,' he said, 'the limited view of the proper range of the inquiry to which the trials are intended to supply an answer, arose from the belief that resistance must be as the square of the speed, and horse power as its cube; and this belief, incorporated into one or other of the well-known *constants*, has survived more or less persistently in spite of attacks and misgivings, and has constituted a self-supported obstruction to new ideas. It is also true, however, that measured mile trials, even as at present limited, are costly experiments, and notions of economy have as-

sisted to damp the ardour of those who have been on other grounds willing to become innovators. But no expenditure ostensibly encountered in the search for truth is really so uneconomical as that which, while it seems to furnish information, helps to support error, and, in fact, "darkeneth counsel by words without knowledge;" and it is to Mr. Denny's honour that, finding the so-called constants were invariably variable and inconsistent, he determined of himself to strike out a new line and find out by means of a trial what is fact, instead of contenting himself with assuming what ought to be the relation existing between indicated horse-power and speed.'

"By the help of those experiments Mr. Froude was able to deduce the fact that the initial friction of a marine engine, constant, or very nearly constant at all speeds, amounts to from one-sixth to one-eighth of the gross load on the engine when the latter is working at its maximum speed and power, while at slower speeds as much as half the indicated horse-power may be absorbed in this way. It also enabled him to build up, as it were, and account for the enormous loss of 60 per cent. of the power expended, which his experiments with the 'Greyhound,' as well as his own model experiments, had shown him does take place in propelling a screw steamer through the water.

"There can be no doubt that Mr. Denny's steam trials and the discoveries made by Mr. Froude thereon, form a landmark in the history of screw propulsion, perhaps the most important one of the present age. It enables us in a measure to eliminate the question of screw propulsion from that of ship resistances, and certainly as the results of trials conducted on the 'progressive' principle become multiplied, we shall be enabled to do this most effectually. It would be a thousand pities—and worse—if the future trials of the Admiralty ships are not conducted 'progressively' instead of merely at full and half boiler power. Some ships have, we are aware, been tried at other speeds, but the thing has not been done systematically. The different speeds have in such cases for the most part been tried on different days and under different conditions, so that a speed curve could not be relied on to the same extent as if the trials were consecutive and formed parts of a series carried out under the same conditions. We regretted much to see that the trials of the 'Iris' were not carried out in this way, because in addition to the valuable results already obtained from her, we should doubtless have gained much further information.

"Nothing can illustrate this more clearly than a brief glance at some of the seeming anomalies brought to light by the Admiralty trials, which are apparently incapable of explanation, but which must have been sooner or later cleared up, if the system of 'progressive' trials had been carried out.

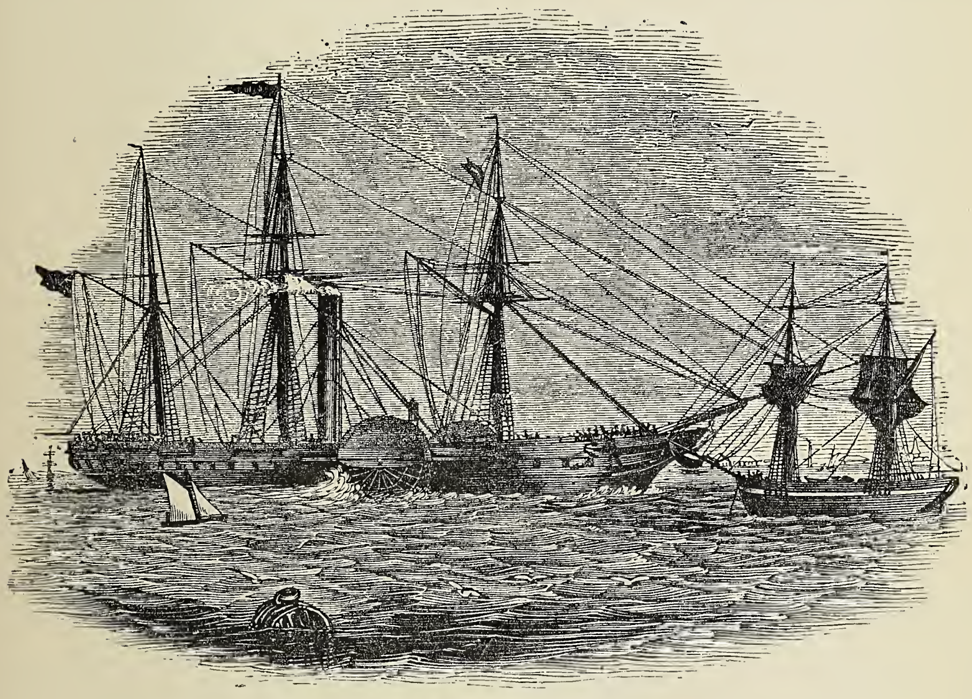


Fig. 201.—The "British Queen," Steam-ship.

"We know the Admiralty "constants" are obtained from the formulæ

$$\frac{\text{Speed}^3 \times \text{displ.}^{\frac{2}{3}}}{\text{I.HP.}} = \text{constant}$$

and

$$\frac{\text{Speed}^3 \times \text{mid. sec.}}{\text{I.HP.}} = \text{constant}$$

and in these formulæ the assumption is made that the resistance varies as the square and the indicated horse-power varies as the cube of the speed.

"Did the indicated horse-power vary as the cube of the speed, of course we should find the same constants for a ship at full power as at half power, but this is never the case, and almost invariably the constants at full power are lower than those obtained at the half-power trials, showing that the indicated horse-power varies as a higher power than the cube of the speed. The assumption has been usually that the work due to resistance varied as the indicated horse-power, so that the lower constants were taken to indicate a higher rate of resistance, and consequently when sister vessels gave constants differing materially from each other the results became more or less inexplicable. Accordingly, if we compare the measured mile performances of sister ships like the 'Warrior,' 'Black Prince,' and 'Achilles;' or the 'Northumberland,' 'Agincourt,' and 'Minotaur;' or the different vessels of the 'Invincible' class; or unarmoured ships like the 'Active' and 'Volage,' we find differences in the results inexplicable so far as the records of the trials can throw light on them. It is not so much that the constants differ in two ships having the same lines, for that might be accounted for by differences in skin surface and other matters, but the rates at which they change in going from say half power to full power is in some cases very marked, without any apparent cause for the same.

"Take for instance the 'Active' and 'Volage;' the constants in the former at half power are 573·9 and 191·3, and at full power 527·5 and 175·8, or a decrease of about 8 per cent.; in the latter the half power constants are 601·0 and 200·3, while those at full power are 478·1 and 159·4, or a decrease of about 20 per cent. Surely here is a difference that is worth clearing up even at the expense of progressive trials. But there are far greater anomalies than this. If we compare the 'Hercules' and the 'Bellerophon,' two vessels sufficiently alike in fulness of lines to justify the assumption that their resistance from 12 knots up to 14 knots would follow very nearly the same power of the speed as each other, we find the 'Bellerophon's' constants only vary about 4 per cent. between half power and full power, while those of the 'Hercules' vary about 16 per cent. And equally astonishing is the fact that the constants of the unarmoured copper-bottomed and comparatively fine-lined 'Inconstant' show a decrease in going from half power to full power as great as the 'Hercules,' and four times as great as the 'Bellerophon.'

"These are extraordinary facts that cannot be accounted for by any analysis of the lines of the ships, and the steam trials do not assist us to account for them. They must of course be due to some marked differences in the friction of the engines or in the efficiency of the propellers, and progressive trials would doubtless in time solve such points much to the advantage of both naval architecture and marine engineering. Many such instances could be given, but they are unnecessary. We will only here allude to one other comparison, viz., between the 'Invincible' as at first tried and the 'Vanguard,' two sister vessels having twin screws. In the latter vessel the constants were reduced in going from half power to full power about 14 per cent., whereas in the 'Invincible' they were actually somewhat increased. Here we believe the 'Invincible's' trial was deemed abnormal owing to the screw propellers not being well placed, or being unsuitable, but progressive trials in such a case would have been invaluable.

"We think we have said enough to show that Admiralty steam trials as hitherto conducted have left much to be desired in affording the means whereby to account for the performances of the different ships. We have not a word to say against the care and accuracy with which they are conducted; it is the system we think at fault through not being carried far enough. We readily admit they are more complete than the great majority of steam trials carried out in the mercantile marine, but at the same time the system of progressive trials inauguarated by Mr. Denny, and rapidly spreading among mercantile ship builders, is one which the Constructors of the Navy will do well to follow, and in fact must follow, if they hope to make their steam trials as serviceable and as instructive as the public have a right to expect, and if they desire, as they doubtless do, to assist in solving the subtle and intricate questions involved in marine propulsion."

From the same source, *Engineering,* we quote the following remarks on Twin Screw-propulsion.

"A branch of marine propulsion that still leaves room for considerable experimental investigation is that which relates to the action of twin screws. Twin screws have often been discussed at the annual meeting of the Institution of Naval Architects and other places, but they have always seemed to us to be making heavy weather in their struggle to get recognised as affording efficient or at least economical means of propulsion. There have always been strong points in favour of twin screws that nobody disputed, and the points against them were for the most part either not proven, or were not regarded as insuperable. The mere fact that with twin screws a vessel would have the means of propulsion left her if one of the engines were to break down, ought to have carried them one would think to the front years ago, if they could compare at all favourably with single screws in point of economy of propulsion. Add to this the power of manœuvring in small circles which twin screws afford, and the advantages of twin

screws over single screws, at least for war-ships, are overwhelming, provided the speed is as great with twin as with single screws.

"Mr. J. Dudgeon used to urge these views years ago with much pertinacity, and as early as 1865 his firm gave interesting particulars of steam trials made with a number of twin-screw vessels built by them, which will be found recorded in the sixth volume of the Transactions of the before-mentioned Institution. In that paper we also have recorded the conviction of the Messrs. Dudgeon as the result of extensive experience with twin screws for mercantile ships, chiefly blockade runners, that they were more efficient as propellers than single screws. They say, 'We fearlessly claim an advantage of at least 15 per cent. over any known method of applying power to a steamer.' In spite of this, however, twin screws did not get the opportunities of distinguishing themselves that they to all appearance deserved, either for war-ships or for mercantile purposes.

"It was not, we believe, that they were tried and failed, so much as that faith in them did not rise to such a pitch as to cause them to be extensively employed, and until this was done, so as to test their capabilities fully, they were bound to remain in the experimental stage, and in this stage they have remained up to the present time, so far as the mercantile marine is concerned. They have, however, to all appearance, got the upper hand at last of the single screw in the Admiralty service for war-ships, and the prediction is hazarded by some that twin screws will continue to succeed against the single screw when sufficiently tested in the broader field represented by the mercantile marine.

"Whether this will be so or not we are not able at present to foresee, but the question is an exceedingly interesting one, and worthy of serious discussion. Where twin screws have been adopted in the mercantile marine they have not so far been attended with much success, except in light-draught vessels. This may have arisen, and doubtless did in some cases arise from the twins screws having been unsuitable; but on the other hand, before accepting the Admiralty experience as conclusive for merchant ships, we have to inquire whether there are not essential differences between the royal and mercantile navies such as might make twin screws advisable for general employment in the former and unadvisable in the latter? Until this is done we are not justified in drawing the conclusion that because twin screws have given better results than single screws in war-ships they are likely to do so in merchant ships. This subject was discussed by Mr. W. H. White, of the Admiralty, in an interesting paper read by him last year at the Institution of Naval Architects 'On the Efficiency of Single and Twin Screw Propellers,' and we are not sure that the figures given by Mr. White, unless more fully discussed, might not raise expectations unduly favourable to the use of twin screws for merchant steamers. The author compared the performances of the single-screw ships 'Swiftsure' and 'Triumph' with the nearly sister but twin screw vessels 'Vanguard,' 'Invincible,' and 'Iron Duke,' showing roughly a gain of about 11 per cent. in favour of the twin screws. The single-screw ships 'Bellerophon,' 'Monarch,' Hercules,' 'Sultan,' and 'Independencia,' were also compared with the twin-screw ships 'Captain,' 'Alexandra,' and 'Téméraire,' showing a mean gain in favour of twin screws of 18 per cent.

"These figures, it will be seen, corroborate the 15 per cent. gain claimed for twin screws by Messrs. Dudgeon in 1865 from their experience with blockade runners. If it could be made at all clear that a similar gain might be counted upon in ordinary merchant ships, the change to twin screws would come, and come rapidly.

"On the other hand, Mr. White instanced the case of a merchant steamer where twin screws had failed, and he showed that the failure was due not so much to her being a twin-screw vessel, as to the screws being unsuitable to her. So far as this case is concerned, then, it must be admitted to afford no argument against twin screws. But how far do Mr. White's figures go in support of them? Twin screws were introduced into the 'Invincible,' 'Iron Duke,' and 'Vanguard,' because their draught of water had to be kept down, and some loss of speed was expected in consequence. The high speed realised by the 'Vanguard' was a surprise for everybody, and it was at first attributed to some remarkable properties of the Mangin propeller. It has since been attributed to twin-screws. We have not seen the point raised yet whether the twin-screw performances were really good, or whether the single screw performances on which the Admiralty predictions were based were indifferent. If the single-screw ironclads have not had draught of water enough to render a single screw efficient, screws twin with larger disc areas might easily beat the single screw, and yet be indifferent propellers."

"Let us examine the matter a little closer. Take, for instance, our swift Atlantic liners, and compare, say, the White Star steamer 'Britannic' with the ironclad 'Monarch.' They have nearly the same load displacement, the 'Britannic' being the heavier, having 8,500 tons against the 'Monarch's' 8,070 tons. The 'Monarch's' measured mile trial gave a mean speed of 14·9 knots, with an indicated horse power of 7,842, while the 'Britannic' can maintain a speed of 15 knots across the Atlantic with 4,900 horse power, or nearly 40 per cent. less power. The draught of water of the two vessels is about the same, and they have both single screws of about the same diameter, viz., $23\frac{1}{2}$ feet. We do not make this comparison to disparage the 'Monarch,' for we know she is necessarily shorter and fuller than the 'Britannic,' and must take a great deal more power to drive her the same speed; but there is this point about the comparison that vitally affects the question of twin screws *versus* single screws, viz., that the 'Monarch' has to deliver nearly twice the horse power of the 'Britannic'

through a screw of the same diameter and disc area. It obviously follows, therefore, that the 'Britannic's' screw might be admirably suited for her horse power and speed, and the vessel might possibly lose considerably in speed by exchanging it for twin screws, whereas the 'Monarch' on the same draught of water with her enormous power, and same diameter of screw, might be pinched up for screw area, and find an immediate gain from twin screws through the mere fact of getting a larger disc area. We doubt if Mr. White has given to this point the prominence it deserves, for it may make all the difference in the world between the prospects of twin screws in the mercantile marine.

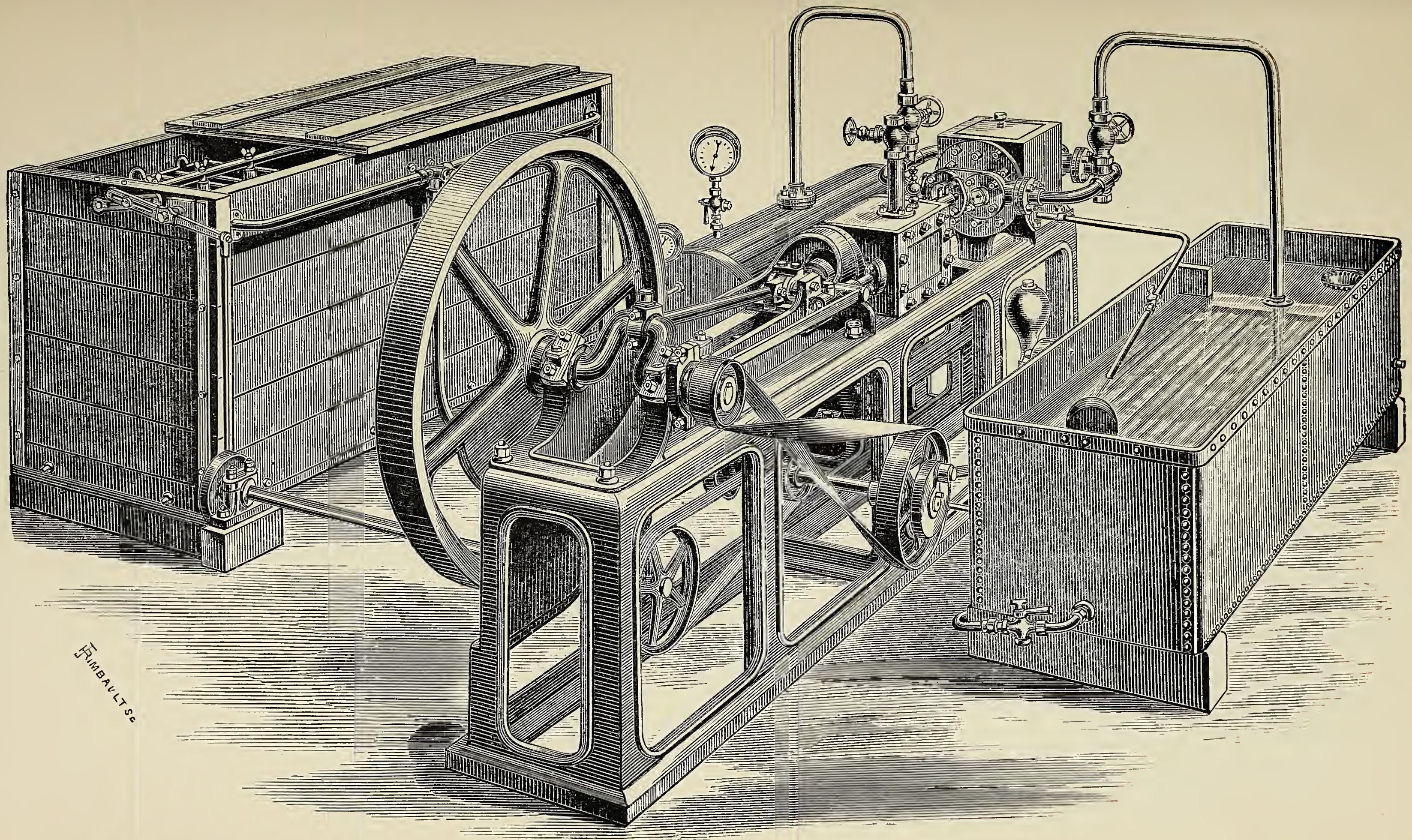
"Speaking generally, we may say of all the modern ocean-going ironclads that aim at thirteen or fourteen knots speed, that owing to their being comparatively short, broad, and full, compared with merchant ships intended for such speeds, they have to carry nearly twice the engine power per ton of displacement, and being limited to about the same size single screws, they, to all appearance, cannot obtain sufficient disc area of propeller to give equally good results. Mr. White says:—'The "Bellerophon" gains relatively to the "Hercules" and "Sultan," not merely because she is rather more finely formed, but because she has a screw of equal diameter, although her engines develop about 25 per cent. less power. This fact suggests the further consideration that since the extreme draught of warships does not exceed twenty-seven feet or twenty-seven and a half feet, there must be considerable difficulties in the way of securing economical performances with single screws in cases where the indicated horse power has to reach 8,000 horse power or upwards, unless the general practice in proportioning the diameters of screws to the indicated horse power is entirely departed from.' The argument might be pushed much further, and it may be asked whether in the large ironclads for which speed results are given, single screws have ever had a fair chance at all of giving high results. If we compare the twin-screw ships with the single screws in Mr. White's Tables, it will be seen that the former have in all cases more disc area per indicated horse power than the latter. If this is a chief cause of the superiority of the twin-screw ironclads, and there is nothing in the paper in question to show that it is not, it destroys in a measure the analogy between them and merchant ships, except where the latter are of unusual type and of shallow draught. But when narrowed down to this, we leave the bulk of the mercantile marine, and come to special types like Mr. Dudgeon's blockade runners and others, for which twin screws have already been recognised as the most suitable means of propulsion.

"Mr. White, in his paper, cites the case of the 'Iris,' and anticipates that 'at no very distant date the designs of swift mail steamers will be subject to conditions resembling those sketched above for the "Iris."' We believe the time is very distant indeed when mail steamers will be subject to conditions resembling the 'Iris.'

"The 'Iris' is very little more than a light hull filled up with engines and boilers. Let us compare her with the most recent development of the mail steamer. And for this purpose we may again take the 'Britannic.' It is sufficient to say that the 'Iris' is only half the size and carries twice the engine power of the 'Britannic,' and carries little else to show the gulf there is between the two. And the 'Brittannic,' being one of the very finest, swiftest, and most modern of our ocean mail steamers, is presumably the nearest to the 'Iris,' so that we may look long for the time when shipowners generally will be compelled to resort to twin-screws, for the reason that prevailed in the case of the 'Iris.'

"If we go from the fast Atlantic liners, like the 'Britannic,' 'Germanic,' 'City of Berlin' and others to the heavy deadweight carrying steamers, the argument deduced from the performance of the Government ironclads becomes still further weakened, for considering the small amount of power put into these cargo steamers they have a still greater abundance of room for sufficient disc area with a single screw. These steamers now form the bulk of the mercantile marine, and they would value but little the extra manœuvring power obtained from their screws, if these latter added to the cost of propulsion. Moreover, in the case of these vessels the strongest point in favour of twin screws loses much of its value. We refer to the vessel being capable of being driven by one set of engines and propeller if the other were to break down. It is unfortunately but too true that in heavy weather, especially in the Atlantic, these steamers can barely hold their own with full power, and they would certainly be nearly as helpless with half-power in a mid-Atlantic storm, and nearly as unmanageable as if there were a total breakdown. Moreover, the feeling of having two sets of engines in case of a breakdown, would tend to give, we believe, a false security to the engineers and all on board, and would probably diminish the precaution taken in overhauling the engines and boilers every voyage to prevent a breakdown —hence from the point of view of safety alone the remedy might be worse than the disease.

"In the foregoing remarks we have said little or nothing about the practical advantages or disadvantages of twin screws, as they are for the most part well understood. Neither have we attempted to show that twin screws must prove less economical as propellers for the mercantile marine than single screws. We are by no means certain on the point. We simply go so far as to say that experience gained with our ironclad war-ships does not settle the matter one way or the other, and might, unless carefully weighed, prove rather misleading than otherwise. Equally misleading would be some of the results we have seen given for twin-screw merchant ships until they have been satisfactorily confirmed, and the same or similar vessels tried with differently proprotioned screws. The 'Iris' starting with a screw of 18 feet 6 inches in diameter, and about an equal pitch, gave very bad results. When the diameter was reduced 2 feet, and the pitch



THE ATLAS ICE-MAKING MACHINE.

increased 2 feet, a marvellous change for the better occurred. The 'Washington' with 15 feet diameter and 20·8 feet pitch gave unsatisfactory results, while in other vessels the screws have say 13 feet diameter, and as much as 21 feet pitch. Here the circumstances are obviously very different, and there is, as we have said, room for much experimental investigation. The trials of the 'Iris' show that it is as easy to get too much area of screw disc and blade area with twin-screws, as it is to get too little with single screws. What is obviously most desirable is as full a supply of data as is possible for ships that have been actually fitted with twin-screws in the mercantile marine, in order that a fuller and more satisfactory comparison might be made with single-screw ships of similar type than is at present possible from published records."

CHAPTER VIII.

IRON MANUFACTURES—MOTIVE POWER: WIND, WATER, STEAM: PUMPS, PUMPING-MACHINERY, FIRE ENGINES, ETC.

HITHERTO, we have presumed that all our readers are well acquainted with the steam engine in its various forms, at least as regards its external appearance, its objects, uses, &c. Half a century ago, such a presumption would have been quite out of place, considering the majority of civilised humanity hardly ever set eyes upon one except during a pleasure trip on board of a steamer. Railways were then unknown to the masses; steam-engines were hidden within the precincts of large factories, and only made their presence known by an occasional boiler explosion. At the present day, such matters are altered. The road-rolling steam machine is familiar in the streets of all large towns; even our grocers' and other shops have their steam engines for grinding coffee, &c; railways and steamboats have their travellers to the extent of many hundred millions of persons annually, and even the schoolboy may, for a few shillings, become the possessor of a steam engine which is only different from those used in the factory, &c., by size and perfection of workmanship.

Certainly the most important application that iron and steel have yet had is in the construction of steam engines and boilers, for the universal motive power of all civilised nations is derived from that source. But there are other forms of motive power that are in use, and to the consideration of these and the steam engine the present chapter will be devoted. We shall take them in the order of wind, as in the windmill; water, as in water-wheels; steam; gas, and hot air, and treat them in the order just mentioned.

Wind-power—Windmills.

As a force applied to the movement of machinery, wind has few advantages, except its little cost after the first outlay for a windmill has been made. It is chiefly available in flat countries, where there is no opportunity of obtaining the preferable power of water, and where there is little interruption to the aerial currents. In hilly countries windmills are often subject to derangement, from the excessive force of the gusts of wind that occur in such regions. In tropical countries, particularly islands and places near the sea-shore, the daily occurrence of the land and sea-breezes, occasioned by the action of the solar heat on the land, provides a certain amount of wind-power, which may be almost always depended on. But in these countries, on the other hand, there often occur tornadoes, or hurricanes of extreme violence, that sweep away almost everything that may oppose their progress; and thus frequently destroy windmills, and occasion renewed outlay in their re-construction. The principal use to which windmills are devoted in temperate climates, is for grinding corn; in tropical climates, such as the West Indian Islands, they are employed for driving sugar-cane mills. In fenny and marshy countries, such as Holland, or some of the eastern counties of England, they are used for drainage, either by working pumps or turning a wheel contrived for lifting the drainage water from the surface of the ground into canals at a higher level, by which it is carried off into the sea. In all situations, however, where the cost of fuel is not extravagantly great, steam-power is gradually superseding that of wind, because its certainty of action more than repays the cost of its production. Whole districts, the drainage of which is dependent on wind-power, may frequently remain many weeks under water from the prevalence of calm weather, and the agricultural operations of the season may be so seriously interfered with, that whole crops are lost, or become immensely deteriorated. In sugar-growing countries, again, the derange-

ment of wind-machinery by a hurricane or tempest, may occur at the season when the sugar-canes have to be crushed ; and the loss of a few days in crushing the canes, may seriously damage the sugar in respect of quantity as well as quality. Upon the whole, then, whenever the cost of fuel is not excessive, it is not advisable to incur the outlay of extensive works for securing wind-power. A very small steam-engine, kept constantly in operation, is far more effective than a windmill of much greater power, because the latter is so variable and uncertain in its action. The only operations suited to wind-power, are such as need not necessarily be completed at certain periods, but may be conducted occasionally as the wind may serve. Nor should the machinery driven by wind require very nice regularity in its action ; for, notwithstanding all the ingenious arrangements for equalising the wind-force, it is still unsteady at the best.

Every part exposed to the wind should be greatly in excess of the strength required to resist the average strain to which it may be exposed. The tempest of an hour—nay, a momentary gust—may frequently destroy a windmill that has stood under ordinary winds for years. As a safeguard against too much strain, the windmill should always be left free to revolve, even if the machinery which it drives be thrown out of gear. The shaft or axis of the mill generally carries a large wheel, to which is fitted a strap of iron loaded so as to press on its circumference, and act as a friction-break either to hold the mill fast for purposes of repair during light winds, or to check its velocity when the winds are too strong for the work required.

It is not at all an easy matter to estimate the powers of windmills. The proper guide as to power, velocity, and construction, is experience. Some of the works of Smeaton contain much valuable information respecting this branch of Practical Mechanics ; and to these we must refer such of our readers as require a more full discussion of the subject than our limits permit us to offer.

At the present day the windmill in this country is becoming quite a curiosity. In the south-eastern counties of England and occasionally in some portions of the midland districts one may be seen by the traveller. But in all large towns there are millers who employ steam alone for grinding corn, and strange as it may appear at first sight, London itself is prominent in possessing steam corn-grinding mills. Even in the very heart of the city itself these mills may be found. As a curiosity representing the old windmill, the engraving Fig. 202 is given, illusing one designed by the celebrated Inigo Jones.

Water-Power.

Formerly water-power was largely employed, and in fact was the chief motive power used for a great variety of purposes. Indeed, at the present day it is largely used where natural circumstances permit, rivers, small streams, and other such cases where water is in constant motion being called into use to drive the various forms of water-wheels, turbines, &c. The movements of water are much more serviceable for the purposes of power, and steady in their operation, than those of air. In level countries, where the streams are slow and languid in their flow, this power is not attainable; but in hilly countries, where the rivers and streams fall frequently from a high level to a lower, water-power is easily obtained, and is most advantageous as a steady, inexpensive prime mover. The most common way of employing water-power is to cause the current to act on the circumference of a large wheel, so as to give it a rotatory motion, which is communicated, by means of shafts and wheel-work, to the machinery required to be driven. Such water-mills are generally used for grinding or threshing corn, crushing bones for manure, raising water to irrigate land ; in mining districts, for crushing or otherwise operating on the ores ; and in manufacturing districts, for working cotton, woollen, or flax machinery. Water-wheels are of three kinds, named according to the mode in which the water-current is made to act upon them :—

1. *Undershot*, when the wheel is fixed over a stream with inconsiderable fall, but considerable velocity.

2. *Overshot*, when the fall of the water is so great that the stream may be directed upon the upper part of the wheel.

3. *Breast-wheels*, when the stream can be directed on or near the middle or breast of the wheel.

1. *The Undershot-wheel* may be best understood by conceiving the action of the paddles of a steam-vessel reversed ; that is to say, while in a steam-vessel the paddles are caused to revolve, and were the vessel fixed would produce a current in the water by their revolution, in the case of the undershot-wheel, the natural current of the water pressing on the floats immersed in it, causes the wheel to revolve. It is sufficiently clear that the power derived from this arrangement depends upon the intensity of the pressure which the water exerts on the floats, and the amount of surface pressed upon. If we suppose the wheel at rest, and its float standing vertically in the water, we may easily compute the pressure on every square foot of its surface by ascertaining the speed at which the water flows against it. This pressure, like that of the wind, is proportional to the square of the velocity of current ; for by doubling the velocity, we bring double the number of particles in contact with the float, and we also double the force of each particle in striking it ; so that, upon the whole, we quadruple the pressure. So, also, by taking three times the velocity, we have nine times the pressure ; and, generally, if we know the pressure due to one velocity, such as one foot per second, we can compute that due to another velocity, such as ten feet per second, by multiplying the velocity by itself, and taking the pressures in those proportions.

We cannot afford space to give rules for the calculation of water-power as obtained by the undershot-wheel.

As the velocity of streams to which undershot-

wheels are applicable is never very great, and as the velocity of the floats should not exceed one-third of that of the stream, such wheels are necessarily slow in their revolution, and can therefore be applied with most advantage, in driving machinery where quick speeds are not required. When it is necessary to convert the slow revolution of the wheel to rapid motions in the machinery, there are considerable losses from the friction of the gearing. For such purposes as that of working pumps or fulling-mills, and generally for slow, heavy work, these wheels are very serviceable. The principal objection to their use arises from the circumstance, that with a stream of average rapidity, very little power is obtained without a very large and cumbrous wheel, involving considerable outlay, and extending over a great breadth of the stream. By making the diameter of the wheel large, no greater power is obtained, except what may be attributable to the more direct action of the water on the floats, which enter and leave the water more vertically when the wheel is large. The circumference of a large wheel should move with the same speed as that of a small one; and, therefore, the greater the wheel, the smaller number of revolutions does it make in a given time. The only way of increasing the power is to extend the surface of the floats. This may be done by making them deeper or wider. Additional depth of the float, even where the depth of the stream permits it, is by no means so effective as additional width; for a wide shallow float enters and leaves the water with ease, while a deeper one presses the surface of the water down in entering, and lifts it up in leaving, and thereby encounters considerable resistance to its motion.

Occasionally undershot-wheels have been made like the feathering paddles of steam-vessels, where the floats are capable of being turned on pivots (Fig. 203) so as to maintain a vertical position while immersed in the water, and thus receive its most direct impulse, while they enter and leave it with the least possible resistance.

When it is considered that twice in every day a great tidal stream flows and ebbs along our coast and in our estuaries, it is surprising that advantage has not more frequently been taken of this enormous power by the erection of undershot-wheels along the course of the tidal currents. In this country tide-mills are rare; and neither their number nor magnitude render them important as sources of power. Occasionally, however, they have been employed with advantage. Where there is a great tidal stream, and consequently a considerable difference between the levels of high and low-water, fixed wheels would be almost useless; for at high-water they would be too much immersed, and at low-water too little. It is in such cases necessary to mount them on a floating stage or barge, so that the whole mill may rise and fall with the tide, the amount of immersion remaining constant. Again, as the tide flows alternately in opposite directions, when it is required that the machinery move only in one direction, it is necessary that tide-mills, in such cases, should be fitted with apparatus by means of which the direction of movement may be reversed; or, where the mill is floated on a barge, the swinging of the barge by the tide effects the required change of position to suit the change in direction of the current.

If it were practicable to make use of the tidal stream in such a river as the Thames, without interfering with its navigation, the power derived from it would be enormous. If we suppose the breadth, 1,200 feet, occupied by tidal mills side by side, with floats immersed 3 feet deep, the total float-surface would be 3,600 square feet in one section of the river. The velocity of current we may take, on the average, as 3 miles per hour, nearly $4\frac{1}{2}$ feet per second; and the power, according to our rule, would be

$$\frac{3600 \times 4\frac{1}{2} \times 4\frac{1}{2} \times 4\frac{1}{2}}{3800} = 86 \text{ horse-power.}$$

Were such mills repeated at intervals of 220 feet along a mile of the river, there would be 24 of them, and the total power would be $86 \times 24 =$ 2064 horse-power in a mile of the river's length. It is not, of course, presumed that such an arrangement is feasible: it is only offered as an illustration of the great mechanical power that might be derived from the natural movements of the water in tidal estuaries. In some rivers, such as the Rhine and the Seine, barges are moored carrying tidal mills of this kind. In such streams the level does not greatly vary, and the current sets continuously in one direction, so that the power is applied with constancy and facility.

2. *The Overshot Water-wheel* (Fig. 204) has its circumference divided by partitions into numerous compartments, or buckets, capable of containing water. The spout conveying the water to the wheel either passes over its summit, or has a check at its end (Fig. 205), so as to discharge the water into the buckets a little beyond the summit of the wheel. As the wheel revolves, each successive bucket is brought under the spout and becomes filled with water, the weight of which, acting on one side of the wheel, is the moving force. The buckets, as they descend, become gradually emptied, and return up the unloaded side of the wheel, to be again filled, and descend.

Such wheels are only applicable where there is a considerable fall of water; for the height of the head, above the stream as it flows away from the wheel, technically called the *tail-water*, must be equal to the diameter of the wheel, or nearly so. In overshot-wheels the velocity of the water is no element of power, except in so far as the quantity conveyed by the spout to the wheel depends upon the velocity with which it flows. If the velocity of discharge be considerable, a positive disadvantage results from the too rapid dash of water into the buckets, causing it to overflow, while the bucket remains only partially filled. It is easy to see that the quantity of water issuing from the spout during the time which a bucket occupies in passing under it, should barely exceed that which the bucket will hold; if it fall short of that quantity, the bucket is only partially filled in its passage;

and if it much exceed that quantity, the force of its flow causes it to dash over and become wasted without effectually filling the bucket. The diameter of the wheel being limited by the height of the fall, when it is desirable to take advantage of a large quantity of water discharged from the spout, the breadth of the wheel must be increased, and the water in the spout caused to spread itself out to a wide sheet, so as nearly to cover the whole breadth of the wheel. The sheet of water should always be a few inches narrower than the face of the wheel, to save the water from dashing ineffectively over the edges (Fig. 206). Another point of great importance in the construction of the buckets, is to leave a passage for air at the inner upper angle of each bucket, *a*, *a*, *a* (Fig. 206), otherwise the bucket can become only partially filled, in consequence of the elasticity of the air confined in it compelling the supply-water to dash over the edges instead of filling the bucket.

In constructing an overshot-wheel it is necessary to give consideration to the following points :—

1. The point of the circumference at which the spout should discharge so as best to fill the buckets.

2. The best form of bucket for receiving the water, and for retaining it, through a considerable part of its descent.

3. The best speed at which the circumference of the wheel should travel so as to obtain the greatest effect from the moving load of water which its buckets contain.

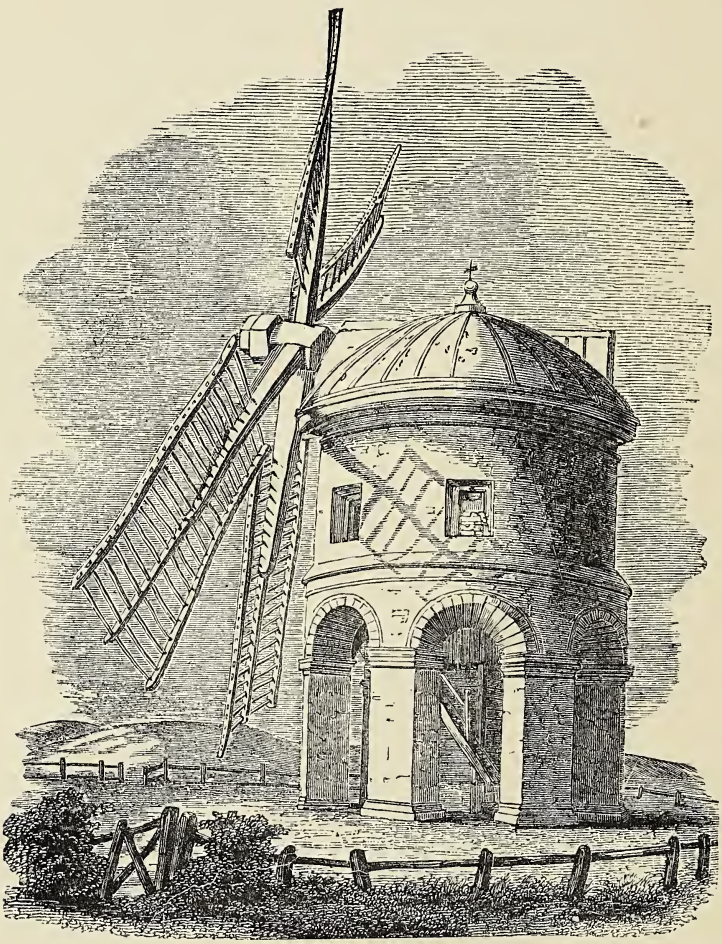


Fig. 202.—Windmill at Chesterton, Warwickshire ; by Inigo Jones.

If we suppose that a fall of water about twenty-two feet in height is to act upon an overshot-wheel (Fig. 207), we may make the wheel about twenty-four feet in diameter, and the depth of the buckets, measured towards the centre, two feet. Dividing this depth into two equal parts, each one foot, marked by the dotted circle (Fig. 208), dividing the circumference of this

circle into a convenient number of equal parts B B equal to the number of buckets (40 in the Fig. 207), and drawing lines C B A towards the centre of the wheel through the points of division, we are enabled to determine the form of the buckets. The casing extending between A A is called the sole of a bucket, and is left with a narrow slit open at A for the escape of air from the bucket when the water pours into it. The board A B is called the start, and the inclined part B C the arm of the bucket. Sometimes this inclined part is made in two

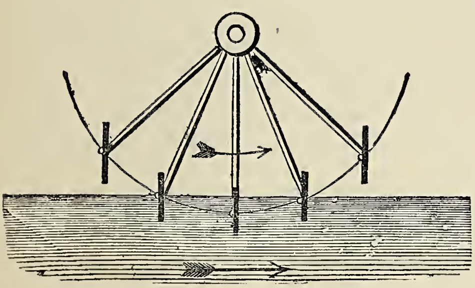


Fig. 203.—Undershot Wheel, with feathering floats.

parts at different degrees of obliquity, like the lines B D, D E ; of which B D would be called the arm, and D E the wrist, the start A B being called the shoulder. These names are doubtless given from the resemblance of the section to the form of a bent arm. The whole circumference of buckets and soles is called the shrouding.

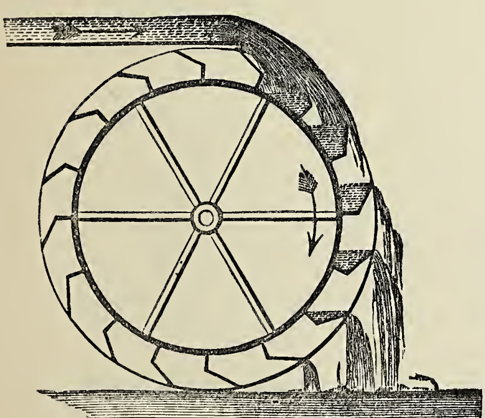


Fig. 204.—Overshot Water-wheel.

On dividing the vertical diameter F G of the mean circle of the shrouding into six equal parts at the points H, I, J, K, L (Fig. 207), and drawing horizontal lines through H and L to meet the circumference, we observe that at the upper line the bucket is filled, and therefore, the weight of its contents begins to act in causing the wheel to revolve, while at the lower line it begins to empty itself, and its action may there be considered to cease ; or whatever effect the water may have beyond this point, is so small that it may be neglected as an element of power. The total effect of the water, then, in causing the wheel to revolve, may be reckoned to be that of the weight of water contained in ten buckets descending through a height equal to two-thirds of the diameter of the mean circle, viz., $22 \times \frac{2}{3} = 15$ feet nearly. The diameter of the mean circle is equal to the height of fall;

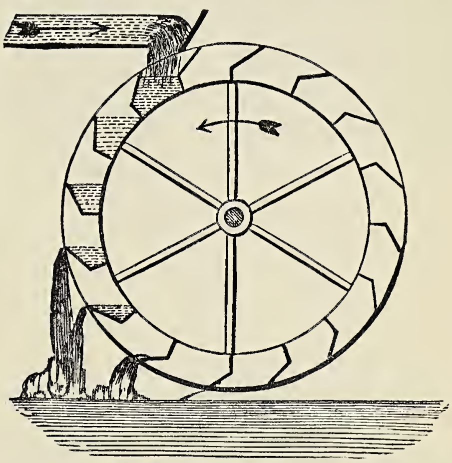


Fig. 205.—Overshot Water-wheel.

and we may, therefore, by taking a wheel of just proportions, generally obtain a descending weight acting through a vertical height two-thirds of the height of fall ; and the weight itself, consisting of the contents of one-fourth of the total number of buckets. The capacity of those buckets for containing water depends manifestly on the breadth of the wheel or the length of the buckets, as well as their sectional area. The area of those in the diagram, reckoning up to the level line bounded by the air-slit at their filling-point, and by the lip of the bucket where the discharge begins, may be taken at little above $1\frac{1}{8}$ square foot ; and we may suppose, for facility of calculation, that their length or the breadth of the wheel is one foot, giving each bucket a capacity for containing $1\frac{1}{8}$ cubic foot of water, weighing about 70 lbs. The contents of the ten buckets, therefore, weigh 700 lbs. ; and this weight is constantly moving with the velocity of the wheel.

It has been stated by some engineers, that as much as 70 to 80 per cent. of the power expended by the fall of water has been made available by means of over-shot wheels; but we are inclined to think that, with the best known construction and proportions, the useful effect does not certainly exceed 70 per cent. of the water-power.

Of late years, many of these wheels have been

made of iron: the partitions of the buckets are constructed of iron plates, bent to a curved form, and the obliquity is made considerably more than in the wooden shrouding of former times (Fig. 209). The diameter of such wheels is made somewhat greater than the height of

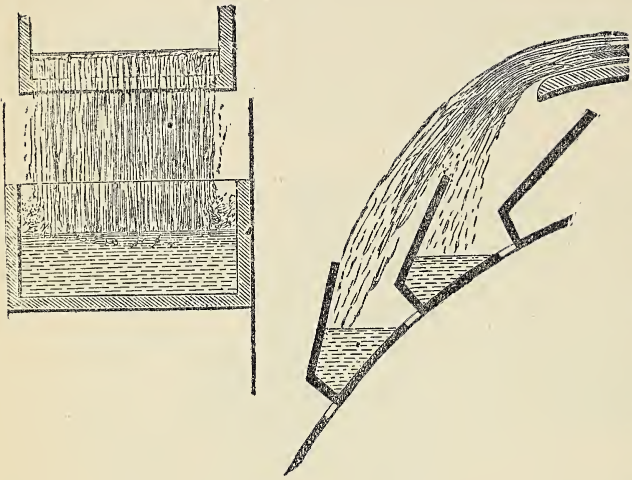


Fig. 206.

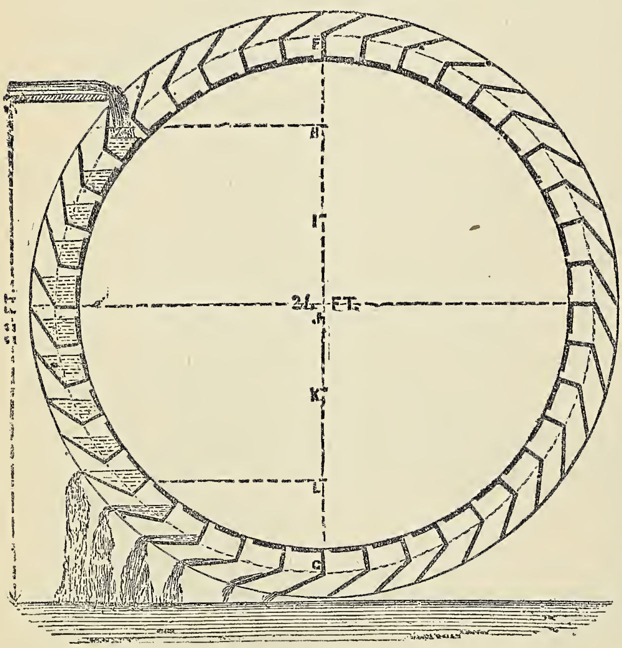


Fig. 207.

fall, so that the water enters the buckets some distance below the summit, where the inclination of the bucket is suited for the reception of the stream. Even if the buckets were filled at the summit of a wheel, and did not empty themselves till they reached the lowest point, the additional effect of their contents would be of little advantage, as it would act more to press the wheel down on its bearings than to turn it round. It will be found advantageous in practice to reckon the diameter of the wheel as $\frac{1}{8}$th more than the fall. Thus, for a fall of 24 feet, we should make the wheel 24 and $\frac{1}{8}$th of 24, 3; altogether 27 feet in diameter.

It has been recommended that the velocity of the wheel should be made dependent on the height of the fall; that is to say, that it should be one-fourth of the velocity which the water would acquire in reaching the bottom by free descent. We can see no reason why such a rule should be observed; for, as we have formerly stated, the velocity of the circumference should be so proportioned to that of the water flowing from the spout, that the buckets may be properly filled during their passage. It is true that, by inclining the spout, we may increase the speed of the stream flowing from it, and thus render a greater velocity of wheel practicable; but, being limited to a certain fall, whatever inclination we give to the spout, we take so much from the height after the water is delivered on the wheel, and consequently reduce the moving weight on the descending side of the wheel. We are, therefore, inclined to adhere to the maxim formerly received among millwrights, that the velocity of the wheel's circumference should not exceed three or four feet per second, and that, perhaps, it would most advantageously be fixed at two to three feet per second.

The number of buckets may be determined by making it double the number of feet in the wheel's diameter; thus, in a wheel 24 feet in diameter, the number of buckets would be 48. According to this rule, the space from lip to lip of buckets would always be about $1\frac{1}{2}$ feet. Where the stream in the spout is wide and shallow, it may be made less; and where the stream is deep, it should be greater. But, practically, its size within a few inches is of no great importance; and we should recommend that a division of the circumference by 6, 8, 4, or such numbers and their multiples, should be made, so as to bring each division nearly to 18 inches. In order to provide for the escape of air from the buckets, it is better to make their width exceed, by several inches at each side,

that of the stream, than to provide air-slits in the sole; for, by this arrangement, each of the buckets may be made to hold a considerably greater quantity of water than when the air-slits limit its depth.

Every precaution should be taken to secure a free flow for the tail-water, as the resistance arising from the immersion of the lower part of the wheel in a languid stream, takes considerably from its effective force. It is better to sacrifice a few inches of head by inclining the tail-course, so as to give the water some velocity (at least that of the wheel) in its escape, than to let it act as a drag on the wheel, by making the tail-course too nearly level.

All descriptions of wheels where the water is received on their circumferences, fall under the denomination of over-shot wheels, even if the water be not shot over their summits; indeed, according to the systems now pursued in rendering water-power available, there is no case where a really *overshot*-wheel should be adopted. Instead of making the diameter of the wheel less than the height of fall, so that the spout could be carried over it, the diameter should always be greater, so that the water may be delivered at some point below the summit. Instead of an overshot-wheel, in some cases an endless chain of buckets (Fig. 210), has been employed for obtaining power from a fall of water. In theory, this arrangement appears one likely to prove more effective than that of the wheel, for the weight of water is retained in the buckets, and acts with constant force throughout the whole descent. Practically, however, the apparatus is not of so substantial and permanent a character as the wheel; the chain has numerous joints, all subject to wear and decay from rust; and when they become deranged, the increased friction and inequality of action considerably diminish the efficiency of the apparatus.

3. *The breast-wheel* is an arrangement intermediate between the undershot and overshot-wheels. It consists of a wheel fitted with floats or paddle-boards round its circumference, revolving with its lower part in a channel which nearly fits it. Each plate has a back-plate or sole, so that the wheel is somewhat like an overshot-wheel, with buckets open on their outer sides. When a considerable stream of water falls over a height not sufficient to render an overshot-wheel applicable, and yet greater than would be required for an undershot-wheel, the breast-wheel is applied with great advantage. The floats fit as nearly as possible, without rubbing-friction, to the bottom and sides of the channel, or sweep, in which they revolve; and thus, after passing the point where the water is delivered upon them, they act almost as close buckets, containing a load of water which urges them onwards.

The breast-wheel is represented in Fig. 211, and is copied from an engraving furnished by Messrs. Appleby and Co., engineers, &c., London.

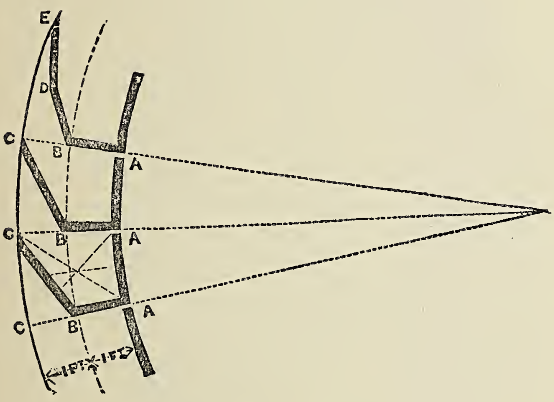


Fig. 208.

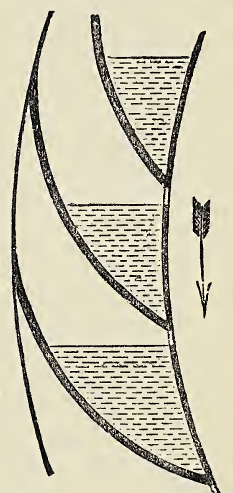


Fig. 209.

In the breast-wheel, at the point where the floats receive the water, some force arises from the impulse or velocity with which the water strikes them, as well as from the mere weight of their contents. Some millwrights have thought this impulse a most essential element of power, and have therefore contrived the spout so as to throw the water on the floats with great velocity. Others, and among them Smeaton, whose opinions on such matters are always to be received with respect, have arranged the spouts so as to deliver the water on the wheel at as high a level as possible. By this arrangement the impulse from velocity is lessened, but the height through which the water afterwards acts by weight is increased.

If we suppose that a certain stream, flowing with a velocity of 8 feet per second, and having a fall of 8 feet, is applied to driving a breast

wheel 20 feet in diameter, having 40 floats (Fig. 212), we may inquire whether it be more advantageous to deliver the stream at once on the wheel, or to slope its course downwards 3 feet before it meets the floats. In the one case we have the impulse due to a speed of 8 feet per second on one float marked 9, and the weight of the water contained in eight others marked 1 to 8 inclusive. In the other case we have the impulse due to the increased velocity of stream upon one float marked 7, and the weight of water acting on six others marked 1 to 6 inclusive. Farther, as in the second case the velocity of the delivered water is greater, its stream must be shallower, and therefore it

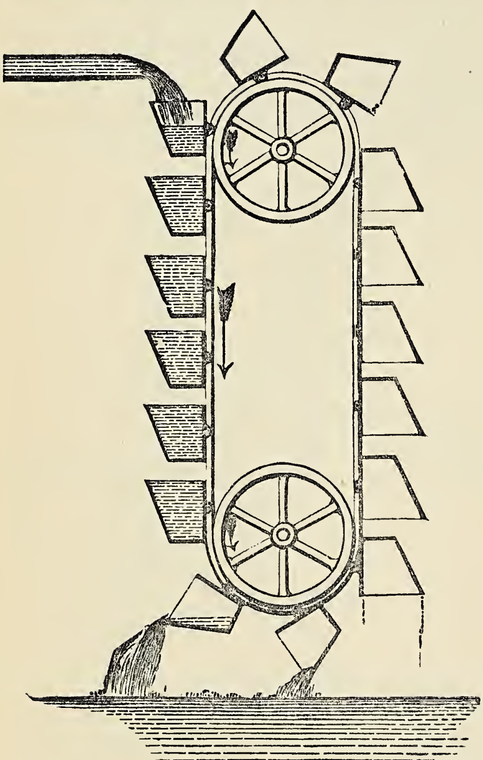


Fig. 210.—Overshot-bucket Wheel.

must strike on a less area of float; and if the wheels move at rates respectively proportional to those of their streams, the same quantity of water being supposed to be delivered in each case, each of the buckets in the second wheel must contain less water than each of those in the first. Let us assume that in each case the wheel revolves at a rate which makes its circumference travel at one-third of the velocity of the stream, which was found to be the most advantageous speed for receiving impulse in the case of undershot-wheels. In the first case the velocity would be $\frac{8}{3} = 2\frac{2}{3}$ feet per second. In the second case we must calculate the velocity of stream due to increased fall. The fall to produce 8 feet per second is 1 foot; and adding to this the 3 feet of additional fall, we have a fall of 4 feet; the velocity due to which is 8 times its square root, or 16 feet per second. The circumference of the second wheel, then, travels at the rate of $\frac{16}{3} = 5\frac{1}{3}$ feet per second, twice the velocity of the first; and if in the first the buckets be exactly filled, in the second they can only be half filled, or need have only half the capacity. If we take the area of float in the first case to be 1 square foot, and in the second $\frac{1}{2}$ square foot, the float marked 9 in the first sustains a pressure due to 8 feet per second, the velocity of the water, less by $2\frac{2}{3}$ feet per second its own velocity; that is, to $5\frac{1}{3}$ feet per second, equivalent to a column $\frac{4}{9}$ths of a foot high on 1 square foot of area, about $\frac{4}{9}$ths $\times 62\frac{1}{2} = 28$ lbs. moving at the rate of $2\frac{2}{3}$ feet per second, or $2\frac{2}{3} \times 60 = 160$ feet per minute, which gives a power of $28 \times 160 = 4{,}480$ lbs. moving at 1 foot per minute. In the second case the float 7 is pressed on by a column sufficient to give 16 less by $5\frac{1}{3}$, that is, $10\frac{2}{3}$ feet per second, which implies a height of $1\frac{5}{6}$ foot; and this pressing on $\frac{1}{2}$ square foot gives 56 lbs. moving at $5\frac{1}{3}$ feet per second, equivalent to 17,920 lbs. moving at 1 foot per minute, 4 times the effect of float 9 in the first case, as might have been surmised, because the velocity is doubled.

It remains now to compute the effect of the remaining floats in producing power. The total quantity of water issuing is 8 cubic feet per second, or $8 \times 62\frac{1}{2} \times 60 = 30{,}000$ lbs. per minute. In the first case this keeps 8 buckets continually full, and moves them at $2\frac{2}{3}$ feet per second, or 160 feet per minute; in the second case it keeps 6 buckets half filled, or 3 buckets quite full, and moves them at $5\frac{1}{3}$ feet per second or 320 feet per minute. As each bucket holds 1 cubic foot, or $62\frac{1}{2}$ lbs., the power of those in the first case is $8 \times 160 \times 62\frac{1}{2} = 80{,}000$ lbs. moving 1 foot per minute; and of those in the second, $3 \times 320 \times 62\frac{1}{2} = 60{,}000$ lbs. Adding to each of these results the power derived from the impulse of the water, we have in the first case 84,480 lbs. moved through 1 foot per minute = 2·54 horse-power; in the second case 77,920 lbs., equivalent to 2·36 horse power. The result is, therefore, in favour of the first case; and thus Smeaton's view of the circumstances is borne out.

If the floats be tolerably well fitted to the sweep, so that there is little loss of water by escape past their edges, the circumferential speed of the wheel should be considerably more than one-third of that of the stream. A rate as high as two-thirds or three-fourths is practically attained with advantage. When this is the case, the impulse from excess of the stream's velocity over that of the float is much diminished, and the principal element of power is the load of the water contained in the buckets. If, then, the fall of the spout be made just sufficient to deliver the water supplied by the stream or reservoir, all the rest of the fall is most advan-

tageously applied in the sweep, care being taken that sufficient fall is left to carry off the tail-water with full velocity so that it do not become heaped up, and retard the ascending floats.

In estimating the power of a breast-wheel, we may suppose, for the sake of simplicity, that the water is delivered on the horizontal line of the centre, and keeps all the buckets, from that line to the bottom, full (Fig. 213). Now the effect of the weight of any bucket, such as A, to turn the wheel, depends upon the leverage with which it acts, which would be measured by the length C B of the horizontal line intercepted between the centre of the wheel and the middle of that bucket. Were we to divide the circumference from D to E into a great number of equal parts, and calculate their combined effect as dependent on the leverage with which they respectively act, we should find it to be the same as if one weight—bearing the same proportion to the total weight in the circumference D E as the length of C D, the radius, bears to the portion of the circumference D E—acted on at D. In other words, the effect of all the weight of water in D E to turn the wheel, is the same as that of a column D F of the same width and thickness hanging at D. The same principle is true if the water do not deliver at the level of the centre of the wheel; for if it be delivered at G, the effect of the weight of water between G E would be the same as that of a column of equal area and of the height G F acting at D.

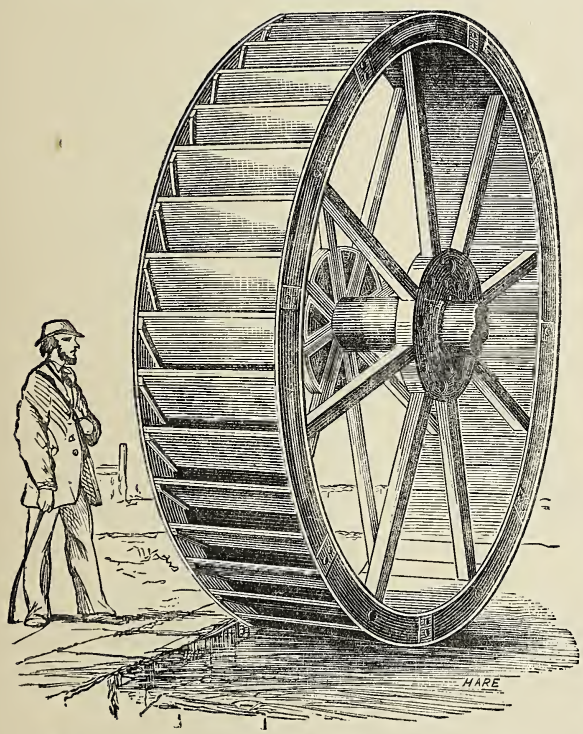


Fig. 211.—Breast-wheel before being fixed into position.

If, now, we take the particular case of a wheel 25 feet in diameter, with buckets one foot broad and one foot deep, receiving the water at the level of the centre, and making three revolutions per minute, we may compute its power, and the proportion which its useful effect bears to the expended power of the water. The buckets being one foot deep, the circle passing through the middle points would have a diameter of 24 feet, and therefore a radius of 12 feet and a circumference of $75\frac{1}{2}$ feet, making three revolutions per minute. The water in the buckets, therefore, moves at the rate of $75\frac{1}{2} \times 3 = 226\frac{1}{2}$ feet per minute; and the weight of the column, having an area of one square foot, and being 12 feet high, is $12 \times 62\frac{1}{2} = 750$ lbs. The power then is $\frac{750 \times 226\frac{1}{2}}{33000}$ = about $5\frac{1}{6}$ horse-power.

The quantity of water required to fill the buckets is $226\frac{1}{2}$ cubic feet per minute, for it must three times fill the whole circumference every minute; and as there must be considerable waste from the inaccuracy with which the floats fit the bottom and sides of the sweep in which they revolve, we may reckon 20 per cent. more, or altogether 270 cubic feet per minute, to cover this waste; that is, $4\frac{1}{2}$ cubic feet per second. If we take the stream at the spout 1 foot wide, and 9 inches or $\frac{3}{4}$ths of a foot deep, its area must be $\frac{3}{4}$ths of a square foot, through which $4\frac{1}{2}$ cubic feet have to flow per second. The velocity of the water must, therefore, be 6 feet per second, or that due to a fall of nearly 7 inches. The water in working the wheel has to descend 12 feet, and we must allow at least 5 inches more of depth at the bottom of the wheel to clear the floats of back water, and the total descent is therefore 13 feet: in other words, in order to raise the water up to the proper level to work the wheel, we should have to lift 270 cubic feet 13 feet high every minute. The power required for this would be

$$\frac{270 \times 62\frac{1}{2} \times 13}{33000}$$

= about $6\frac{2}{3}$ horse-power. We found the effective power of the wheel about $5\frac{1}{6}$ horse-power; that is, 77 per cent. of the power expended. We believe that, practically, this estimate would be found too high, and that we could not depend on obtaining, in useful effect, more than 60 to 70 per cent. of the water-power expended.

The terms *undershot*, *overshot*, and *breast-wheels*, have been applied in a somewhat different way from that in which we have used them. The term *undershot* has been used when the water is delivered on the wheel anywhere below the level of its centre, and thus the wheels which

we have callen *breast*-wheels would be among the *undershot;* the term *overshot* has been used in those cases only where the spout is actually carried over the summit of the wheel ; and the term *breast* has been applied to wheels where the water is delivered somewhere above the central level. We think, however, that the classification we have adopted here is more distinct, as it refers not only to the different points where the water is delivered, but also to differences in the construction of the wheels. Thus, the *undershot*-wheel is that which receives the water-pressure on simple paddles or floats immersed in the current, and is acted on by its force only; the *overshot*-wheel receives the water at a high level in buckets formed in its circumference, and is moved simply by the weight of water contained in them; the *breast*-wheel receives the water on paddles or floats nearly fitting a sweep in which they revolve, and is thus put in motion partly by the weight of water lodged on and between the floats, and partly by the pressure on the floats arising from the velocity of the current. The peculiar construction of each kind of wheel is adapted to different conditions of the fall of water.

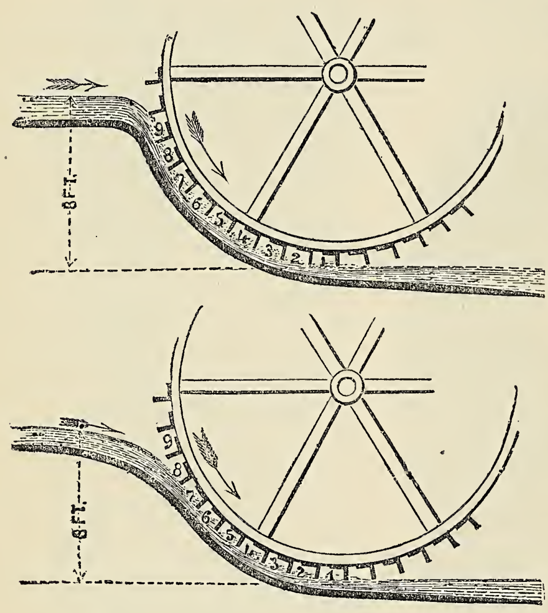


Fig. 212.

The undershot-wheel is to be used when there is a volume of water moving with considerable velocity, but with very little local fall, as in the case of river streams and tidal currents. The velocity of the current of a river arises from numerous little falls, or from a continuous inclination, without any considerable difference of level within a limited space. The velocity of a tidal current, again, arises from the pressure of the tidal wave, or body of ocean water, elevated above its average level by the gravitating influence of the moon ; but this wave appears only as a gentle and almost imperceptible inclination of the water surface, except in some estuaries, such as the Solway Frith, the mouth of the Severn, &c., where it presents itself as an elevated body of water rushing with considerable velocity towards the land.

The overshot-wheel is applicable when the water has a considerable local fall, nearly equal to the diameter of the wheel ; and the breast-wheel when the local fall is not great—less, for instance, than half the diameter of the wheel—but when it is of considerable volume, and moves with considerable velocity. In order to apply either an overshot or a breast-wheel, it is generally necessary to make extensive arrangements for conducting the water from an elevated level to the wheel, instead of permitting it to follow its natural channel. When a stream has a considerable fall—such as 40 or 50 feet in each mile of its length—a dam or weir is built across it at some convenient position, so as to check its progress there, and a new channel is formed for conveying its waters to the mill, and thence back to the bed of the stream at some point below the dam. As the artificial channel is made with only sufficient declivity to secure the flow of the water in such quantities as may be required, it is thus possible to obtain at the wheel, nearly the total fall which the channel of stream has, estimated from the point where the dam is built, to that where the tail-water of the mill re-enters. If, for instance, the stream in its natural channel is found to have a fall of 60 feet in a mile—this difference of level being made up either of numerous small local falls or of a continuous declivity, or both—an artificial channel is formed by its side, or as near it as the levels of the ground permit, having a constant declivity for half a mile, amounting to 5 feet of difference of level; the water acts on a wheel with a fall of 20 feet, and a declivity of 5 feet is allowed in the length of the tail-course. The difference of level in the channel for half a mile—that is to say, 30 feet—is thus made up, and the power due to two-thirds of that fall is thus secured for driving machinery. The current of the stream of itself would probably not have so great a velocity at any place as to make it practically available for an undershot-wheel, on account of the irregularities of its channel, and the numerous resistances opposed to its progress.

Turbines.—When the volume of water is small, but the fall considerable, an apparatus called a turbine is frequently applied with great advantage. The principle of its action is similar to that of the well-known firework called the Catherine-wheel, or of the revolving jet sometimes applied to fountains. For a considerable period it has been known as a philosophical toy, called Barker's mill. This consists of a vertical

tube, with two horizontal branches closed at the end, mounted on a vertical axis on which it can freely revolve (Fig. 214). Near the extremity of the horizontal arms, holes A A are made on opposite sides; and when water is poured into

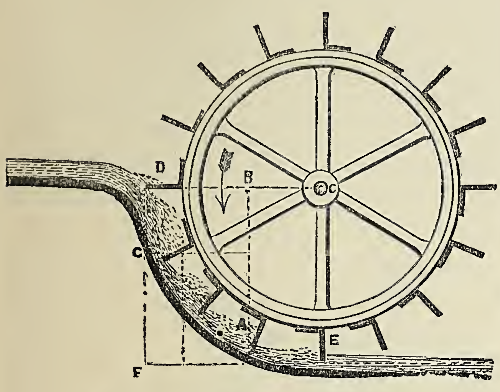


Fig. 213.—Power of a Breast-wheel.

the upper part of the tube, it flows through these holes, and makes the arms revolve in the opposite direction. The cause of their motion may be very simply explained. If we suppose the apparatus at rest, and the holes closed, when the tube and arms are filled with water, every square inch of the inner surface of those arms is equally pressed on by the column of water in the vertical tube; for it is the property of fluids to communicate pressure equally in all directions. Under these circumstances, there is no tendency to produce motion in any direction; but if the holes A A be opened, then, while the pressure on one side of the tube B remains the same as before, that on the other hand is lessened by as much as its surface is diminished. If we suppose each hole to have an area of one square inch, then each side of the tube B sustains a pressure on one square inch more than the other side; in other words, there is a pressure on B exceeding that on A by that due to the area of the hole in A. This excess of pressure causes motion in the direction in which it acts—that is, opposite to the flow of the water issuing from the holes; and the force of the movement depends upon the amount of unbalanced area in each arm, and the intensity of pressure upon it.

In the simple Barker's mill there is considerable loss of power from impediments to the flow of the water. The water descending the tube with considerable speed, is suddenly arrested at O, and spread out laterally; losing by this angular bend a considerable part of its velocity. For the same reason it again loses speed in issuing from the holes A A; and, farther, a considerable part of the power is expended in giving the

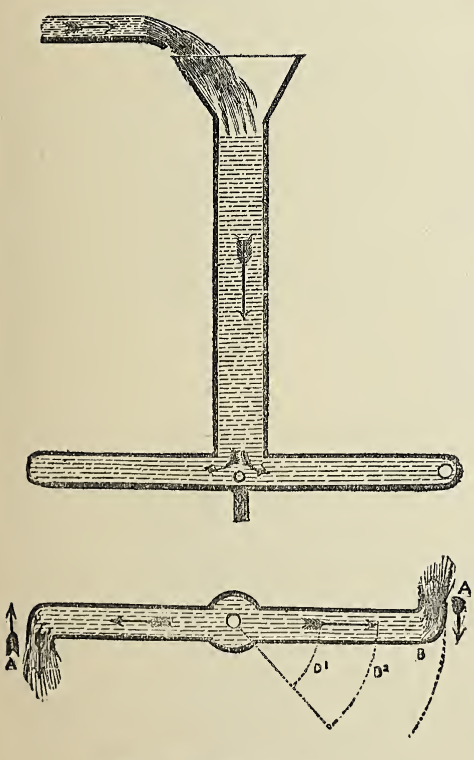


Fig. 214.—The Turbine.

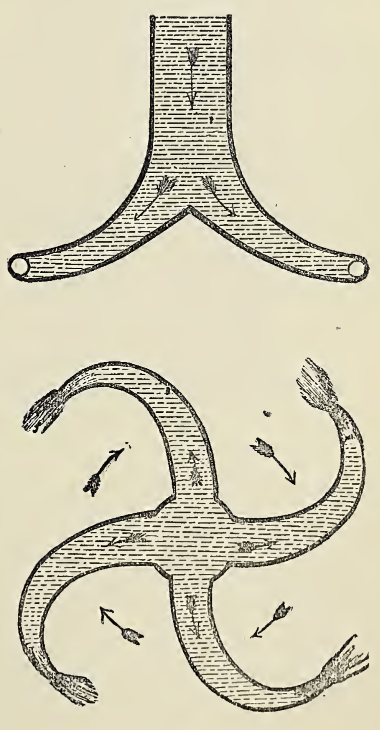


Fig. 215.—The Turbine.

water a circular motion as it passes along the arms. A certain weight of water, as for instance 2 lbs., having descended the tube to O, has merely vertical motion; half of it (1 lb.) has suddenly to be turned at right angles along each horizontal branch, and is immediately put into circular motion with the arm in its revolution, as well as direct motion along the arm. The farther it flows along the tube, the more rapid is its circular motion; for if we take any points D_1 D_2 along the tube, and trace circles through them, we observe that the circumferences of these circles increase as their radii; and as each of the circumferences is passed over in the same period, the time of a revolution, the circular velocity of the water at each point increases in like proportion. In order to obviate these defects, the form of the tube and its arms is modified. Thus, the arms turn from the vertical to the horizontal direction by a gentle curvature, as seen in the section (Fig. 215), gradually changing the vertical movement of the water into a horizontal movement with little loss of force. And again, the arms, of which there may be any convenient number, bend also horizontally, as seen on the plan; so that while they revolve, the water contained in them is really moving almost in a straight line, instead of being swept round in a circle.

As the mouths of the arms must be made of such an area as to permit the issue of the water at the proper velocity due to its fall, if they are made too small, less water passes them than can be supplied, and the machine is not so powerful as it might be with the given supply of water. If, on the other hand, the mouths are made too large, the velocity of the issuing water is diminished; and the pressure on the opposite sides of the arms tending to drive them round, is diminished with it. The area of the mouths being decided according to the quantity of water, and its velocity from vertical fall, the arms are made to taper gradually to that area, so that the velocity of the water may gradually increase to suit the gradually diminished area of its channel, as it would naturally do during its vertical descent. Due consideration having been given to these points, as well as to the best mechanical arrangements for strength, durability, and economy of execution, the machine becomes a turbine, practically applicable in many cases with great advantage. M. Fourneyron in France, and Messrs. Whitelaw and Stirrat in Scotland, have executed many of these machines, and made interesting experiments on their power and the best modes of constructing them. Their simplicity and efficiency, and the small space they occupy, give them an advantage over water-wheels; and it is said that they are capable of deriving from a fall of water, quite as much

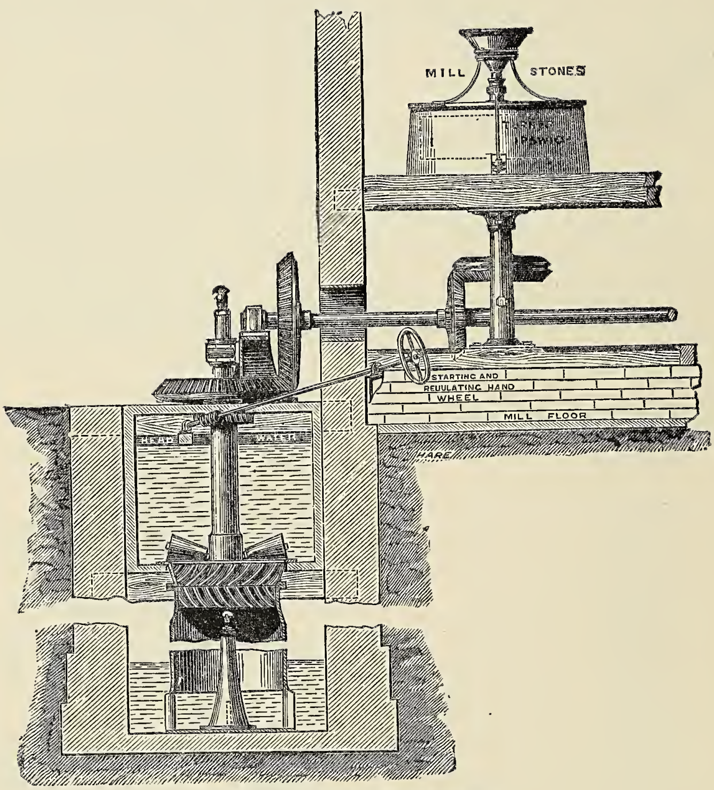


Fig. 216.—The Jonval Turbine.

effective power as wheels of the best construction, even if the volume of water be large. Experiments conducted by Morin in France, lead to the conclusion that turbines are actually more effective than wheels under similar circumstances, the useful effect averaging from 70 to 78 per cent. of the power of the water. It has been found that even the immersion of the arms to a depth of several feet in water does not materially affect their action ; so that even greater height than that of the fall, measured to the level of the tail-water, can be taken advantage of.

In estimating the power that may be derived from a given fall by means of a turbine, $\frac{3}{4}$ths of the power required to raise the water up again, may be reckoned as the usual effect. Thus if the volume of water be 16 cubic feet per second, and the fall 15 feet, the power required to raise it would be $\frac{16 \times 60 \times 62\frac{1}{2} \times 15}{33000} = 27$ horse-power; and the power of the turbine to drive machinery may be taken at $\frac{3}{4}$ths of 27, about 20 horse-power. The power of the turbine is found to be very nearly proportional to the quantity of water passing through it ; so that having found its maximum power, or the greatest quantity of water that it will use, we can employ $\frac{1}{2}$ or $\frac{3}{4}$ths of that power by reducing the supply of water to $\frac{1}{2}$ or $\frac{3}{4}$ths of the maximum.

For the above and following cuts (Figs. 216 to 221) and the descriptive matter we are indebted to Messrs. Appleby, of London, who have made this class of water-motive power a special feature of manufacture. They remark as follows :—

"*The Jonval Turbine.*—This engine, represented by Fig. 000 is adapted for low falls, and is available for driving a set of millstones, or any other class of machinery. In another form of this turbine the water acts perpendicularly or parallel with the vertical shaft, directed through an annular ring of guide blades, set at the required angle, and impinging against a series of vanes fixed at an opposite angle on the circumference of the revolving wheel. The power is regulated by partially closing the water passages through the guide blades.

"*The Vertical Vortex Turbine.*—Figs. 217 to 221 represent various forms of the vortex turbine, invented by Professor James Thomson. The water is admitted at the circumference, and after it has expended nearly all its energy, it passes out at the centre ; this is exactly the reverse of the action of the Fourneyron turbine. Professor Rankine speaking of the vortex turbines, said :—'In every form of turbine a whirling motion is given to the particles of water before they begin to drive the wheel, and the efficiency of the turbine depends on the completeness with which that whirling motion is taken away from these particles during their action upon the wheel. By discharging the water from a part of the wheel whose motion is comparatively slow, the practical fulfilment of that condition is rendered more easy and certain. The action of centrifrugal force in regulating the speed is as follows : Should the load be sud-

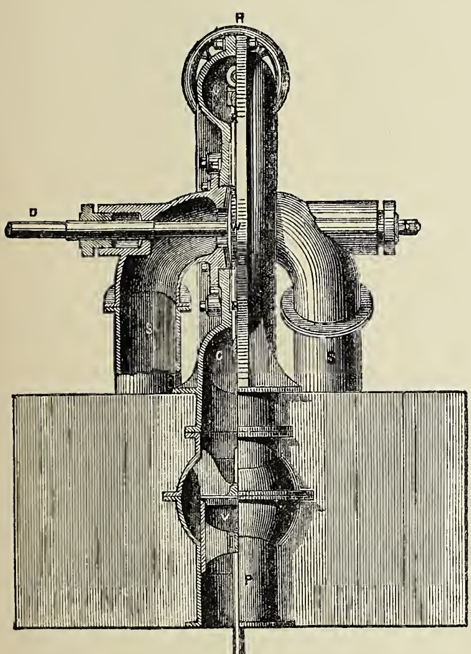


Fig. 217.—The Vertical Vortex Turbine.

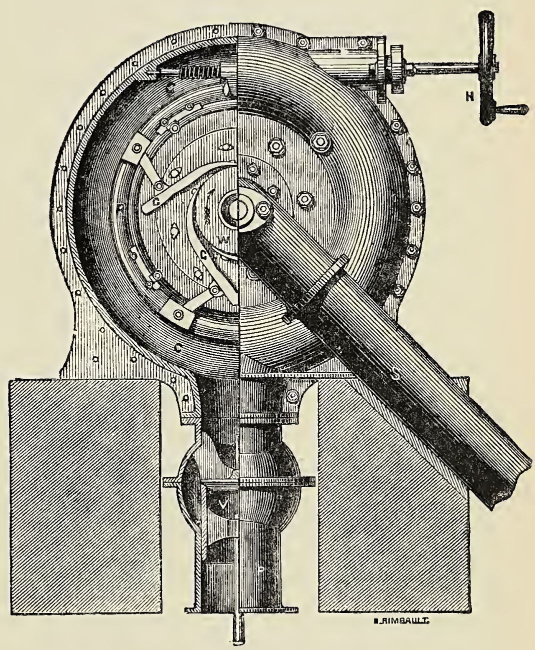


Fig. 218.—The Vertical Vortex Turbine.

denly diminished, and the wheel begin to revolve too fast, the centrifugal force of the water whirling along with it increases and opposes the entrance of water from the supply chamber ; on the other hand, should the load be suddenly increased, and the wheel begin to revolve too slowly the centrifrugal force of the water whirling along with it diminishes and allows more water to enter from the supply chambers, and thus sudden variations of the load are prevented from causing excessive fluctuations in speed, the whirling water acting as a governor. In outward-flow turbines the centrifrugal force of the whirling water acts in the contrary way, and tends to increase the fluctuation of speed. In parallel flow turbines it has no sensible action of either kind.'

"These turbines can be arranged in such a manner as to admit of regulating the quantity of water passing through them. The mode adopted for regulating the water supply is such that the passages are always smooth and of a continuous form, and are free from contraction, thus causing less waste of power than regulation by sluices and valves.

"In Figs. 217 and 218, one half of each view is in section, showing the internal arrangements. The water enters through the pipe P into the annular chamber C, from whence it is conducted by four guide blades G G into the revolving wheel W, and is discharged at the centre. The two suction pipes S S convey it to the tail race. The revolving wheel W, is keyed on the main driving shaft D, an equilibrium valve V is placed on the supply pipe for shutting off the water. The guide blades G G are hinged at their inner points, which enables their angle to be varied by a series of motions actuated by the hand wheel H.

"As mentioned before, this arrangement is only necessary when the power required varies considerably at different times, and saving water is an important consideration ; but when the power required is constant the guide blades are made fixed. The wheel may be placed at any height less than thirty feet above the tail race, and the fall rendered available by the suction pipes, as shown in the engraving. Fig. 219 illustrates the position in which this wheel is sometimes placed, a portion of the fall being obtained by cutting below the level of the mill floor. In this case suction pipes are not required. A A is is the supply pipe, B the wheel, S S the driving shaft. A slide or sluice is provided for closing the conduit D (which leads to the tail race), when it is required to examine or repair the wheel. The bearing block of the toe step is usually formed of lignum vitæ when it is for use under water as in the cut (Fig. 219). Figs. 220 and 221 are perspective views of horizontal and vertical arrangement of the vortex turbine. The power from the horizontal turbine is taken by means of bevil-toothed wheels, whilst that from the vertical one is conveyed by a pulley and leather belting."

Pumps, Pumping Machinery, &c.—Under the designation of *pump*, a vast variety of contrivances, intended to raise water and other liquids from wells or reservoirs, whose surface is below the pump, or to force them to a height much above that surface, has been included. In the following pages the actual pump must be considered as of two kinds, viz.—the *lifting pump*, such as is in common use for raising water simply to the surface of the ground or at a level a little higher, and the *force-pump*, which after having raised the water drives it to almost any desired height as seen in the fire-engine. In the common lift pump is a barrel in which fits, as accurately as possible, a plunger or piston having a valve that opens upwards; beneath this, at the bottom of the barrel, is another valve also opening upwards and covering a pipe that leads into the well. When the plunger is forced down, the air in the barrel forces the valve of the piston upwards, and escapes, while the valve covering the pipe that leads to the well closes. But as soon as the plunger is raised the valve in the plunger closes and that over the pipe opens. The water from the well thus rises and fills the barrel. If the plunger be then forced down, the valve in the piston opens, and that over the pipe closes, and consequently, the water escapes and may be received in any required vessels, or to be allowed to run away.

The reason that the water rises up the pipe into the barrel of the pump is this :—The atmosphere presses on the water-surface in the well with a force or power of about 15 lbs. per square inch. When the plunger of the barrel is raised a vacuum is produced in the barrel. Consequently, the water is forced up the pipe by the pressure of the atmosphere, and thus the operation of pumping is carried on. But if the height from the surface of the water to the barrel exceeds thirty-two feet, the operation ceases, because a volume of that height just about balances a column of atmospheric air, giving the pressure above mentioned.

Hence another contrivance called the *force-pump* is necessary if the water has to be raised any considerable height. In this pump most of the arrangement are similar to those of the lift-pump, but the water instead of being allowed to run away is driven into a vessel containing air. The latter is compressed, and then acts with great force on the surface of the water, driving it to almost any required height. It is on this principle that the fire-engine is constructed, as already mentioned, the details of which will be afterwards described.

Before entering into a description of various forms of pumps, generally of complicated structure, we may briefly notice some contrivances that have become obsolete, but are yet of much historical interest, as having been the foundation of many of the most valuable arrangements of the present day.

A very curious mode of raising water, adopted, or at least suggested, by the ancients, was by means of what is termed the "Archimedean screw." This screw (Fig. 222) is formed either of a flexible tube open at both ends and wound spirally on the exterior surface of a cylinder; or it may be a plate of metal coiled about an axis, like the threads of a screw, and enclosed within a hollow cylinder so as to be completely

water-tight. The machine is fixed in an inclined position, with its lower end immersed in the water which is to be raised. While it is at rest, the water occupies the lower part between two of the threads or bends of the spiral, at the bottom ; but, when turned on its axis, this part of the machine being made to ascend, the water will by its gravity be made to descend into the lower part between the next bends of the spiral, while in reality it rises with respect to its former position, in consequence of the rotation of the tubes or bends within which it is confined. The water becomes by this means worked up to the top, and is there received in any convenient vessel. Sometimes the same object is attained by the use of a pipe wound spirally about the surface of a cylinder, which is made to revolve on its axis when the latter is in a horizontal position ; at one extremity of the spiral, water and air in nearly equal quantities being allowed to enter, the former will, in consequence of the revolution, be forced up an ascending pipe which may be attached at the other extremity.

The *chain-pump* (Fig. 223) is a mode of raising water sometimes adopted, when the quantity to be raised is considerable, and the depth also considerable. There is a chain, carrying a number of flat circular pistons or boards, which passes round a wheel at the upper extremity of the machine, and sometimes also at the lower: each piston, as it goes over the wheels, being in part received in the intervals between the radii. The wheel being put in motion, the pistons descend in a barrel on one side, and enter from below into another on the ascending side ; and thus, pushing the water before them, they raise it into the upper reservoir. If the wheel is turned with considerable velocity, the barrel will be generally quite full of water. The lower end of the barrel dips into the water which is to be raised ; and there are small holes through which this water enters the barrel.

The Persian wheel (Fig. 224) is a convenient means, very much adopted in the East, of raising water for the purpose of irrigation. The wheel must be of greater diameter than the height to which it may be necessary to raise the water, and must stand in the stream or reservoir from which the water is to be taken. On the circumference of the wheel are a number of buckets or boxes, so hung as constantly to maintain an upright position while the wheel is revolving; and these buckets, dipping successively into the water at every revolution of the wheel, bring up water each time, and pour it out into any reservoir or channel prepared for its reception. In Asia it is customary to keep the wheel revolving by means of another toothed wheel, worked by an ox ; but any other mechanical means would suffice, if more convenient.

A few years ago, attention was directed to a curious contrivance, called the "Hydraulic Belt," a specimen of which was exhibited at the Polytechnic Institution, London. The action of this machine depends on the attraction of water by fibrous or textile materials, to such a degree as to cause the fibres to act as a channel of communication for the water, somewhat similar in principle to the action of the tongue of a cat when the animal is lapping any liquid. The fibres thus act as a pump ; and there are two ways of attaining the object in view—by a *rope* pump and by a *belt* pump. In the former of these there is an assemblage of two, three, or more ropes passing over pulleys fixed at the top and bottom of the space or distance through which the water is to be raised ; the ropes are about an inch apart ; and when the pulleys are made to revolve, the ropes (dipping into water at the bottom) carry up with them a column of water, which by a peculiar contrivance is conveyed into a reservoir at the top. It has been stated that a pump of this kind on one occasion raised nine gallons of water in a minute, from a well about a hundred feet deep, by the exertions of one man. In the belt-pump or machine, there is, instead of a pump of ropes, an endless woollen band or belt, passing over two plain rollers, one placed in the water which is to be raised, and the other at the spot where the water is to be discharged ; both of the rollers revolve on their axes ; and as the belt is stretched lightly over them, if one be made to revolve, the other revolves likewise : and the belt thus travels up and down alternately. When the upper roller, by being set in motion, is made to revolve with rapidity, the ascending band carries up a considerable quantity of water, which is discharged at the top by the pressure of the belt on the upper roller, and passes into any convenient receptacle.

Instances of various other methods might be described as formerly in use, but we now turn to those of a modern date, the manufacture of which has been brought to a high condition in reference to economy of working, and space occupied.

The hydraulic ram is an ingenious contrivance, by which a small fall of a considerable body of water is made to raise a much smaller volume of water to a considerable height. From a reservoir A (Fig. 225), at the height of a few feet above the lower level of the stream at B, a large pipe conducts the water ; this pipe has an aperture D, on its upper side near to its lower end, and the aperture is closed by a valve opening upwards, into an air-vessel, from which a small pipe F leads to a cistern at a level considerably above that of A. At the lower end of the inclined pipe there is a hinged valve E, opening inwards, and kept open by a weight fixed on a lever projecting from the valve. This weight is adjusted nicely, so as to counterbalance the pressure of the water on the surface of the valve E, but not greatly to exceed it. When the weight opens the valve, the whole of the water in the inclined pipe C begins to flow downwards, and issue at the opening made by the valve at E. Having acquired a certain velocity, it presses with greater force on the valve, and closes it in opposition to the weight, thereby completely arresting its own flow ; but the momentum of the large body of water flowing along the pipe C cannot be suddenly destroyed,

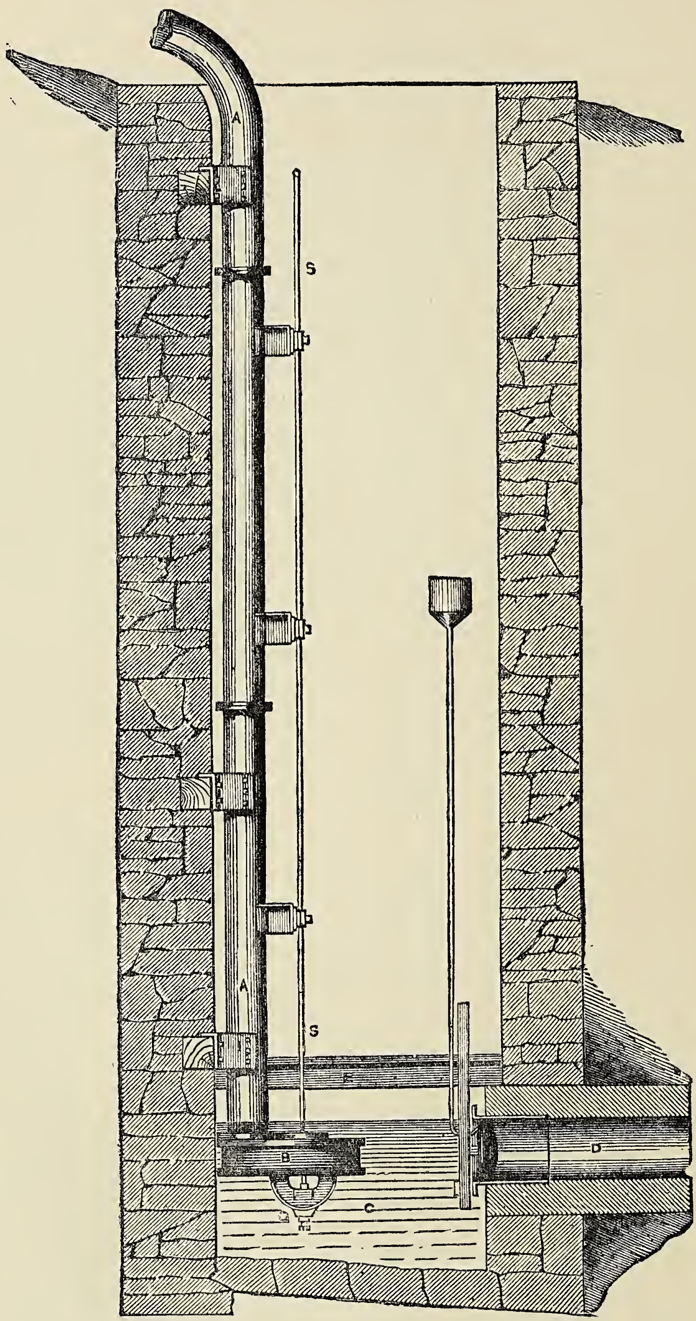


Fig. 219.

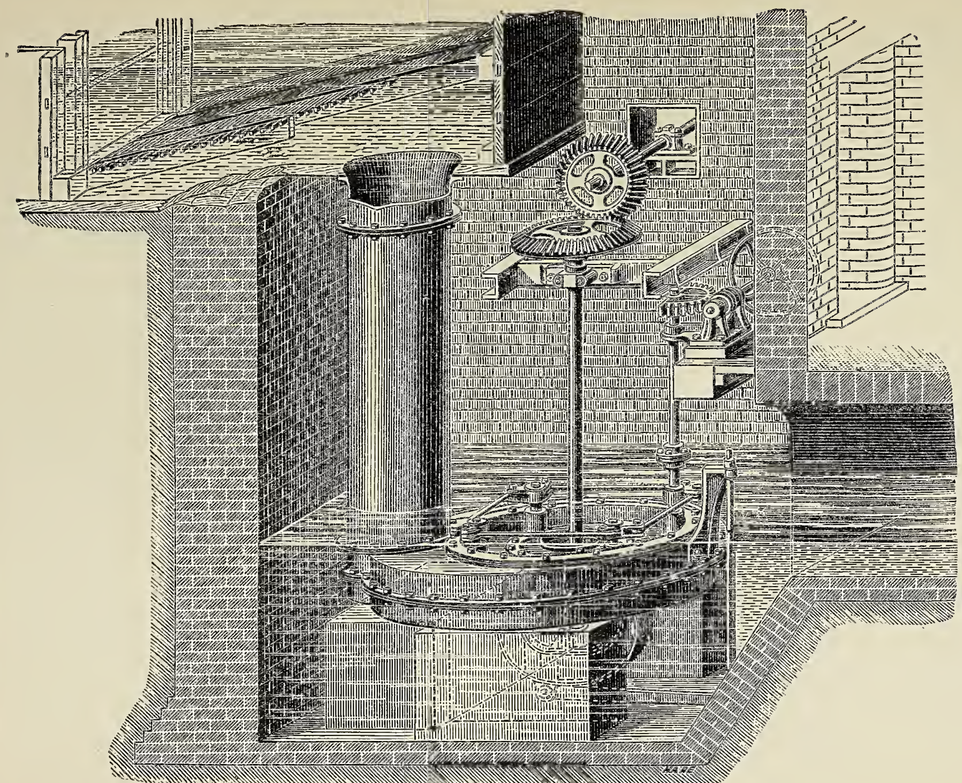


Fig. 220.—Vortex Turbine, fixed horizontally at the bottom of the fall.

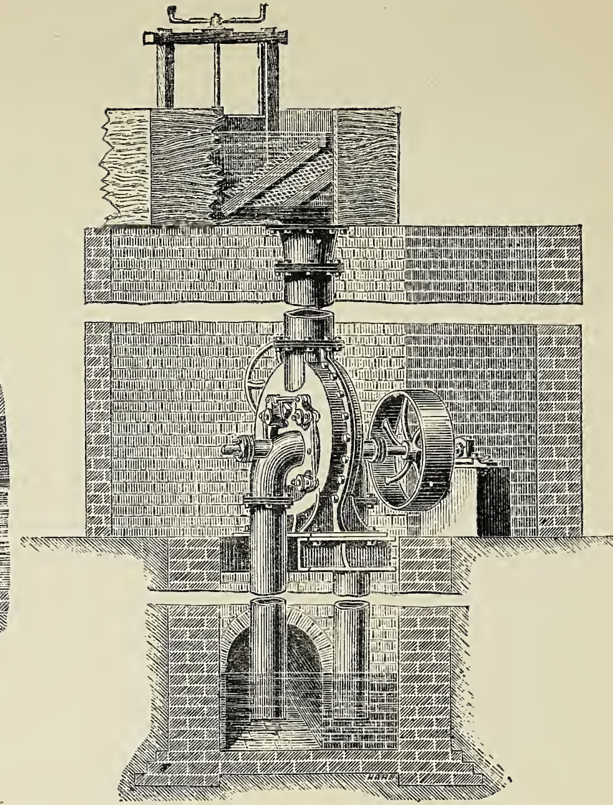


Fig. 221.—Vortex Turbine, arranged vertically, with part of the fall acting by suction.

but must expend itself somewhere. It therefore lifts the small valve D with considerable force, and part of it flows into the air-vessel and up the pipe F. The momentum being thus absorbed, and the water in the pipe C having become still, the valve E again is opened by the weight, and the operation is repeated. Thus, by the alternate opening and closing of the valve E, under the quiescent and moving pressures of the water, a certain portion of the water is forced up the pipe F, and is prevented from returning by the closing of the valve D. The object of the air-vessel is to provide an elastic spring for the water propelled upwards: every time that the water is injected into it, the air in its upper part is compressed into a smaller space; and being perfectly elastic, tends to resume its former volume. It therefore exerts a pressure on the water, and continues its flow along the pipe F during the intervals that elapse between the successive discharges through the valve D. In estimating the power of this apparatus to raise water, we may suppose it arranged with the flow-pipe vertical instead of inclined, as it is usually made for convenience, the principle not being altered, but the details of calculation simplified by the vertical arrangement (Fig. 226). We may suppose

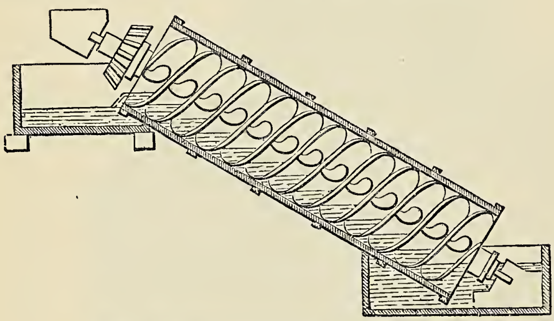


Fig. 222.—Archimedes' Screw.

that the height from the valve to the surface of the water in A is 4 feet, and that the area of the valve E is 1 square foot. The pressure on the valve is, therefore, the weight of 4 cubic feet of water; namely, $4 \times 62\frac{1}{2} = 250$ lbs. The effect of the weight to lift the valve by means of its lever must be somewhat greater than this. If the valve could be suddenly lifted so as to leave an opening to the full extent of its area, 1 square foot, the water would descend in C at the rate of 16 feet per second, the velocity due to 4 feet head; but as the valve opens gradually, and is only open for a short time, and that not to its full extent, we may take the velocity of the descending column at not more than $\frac{1}{4}$th of this rate; this is to say, at 4 feet per second. When this movements ensues, the valve is pressed on not only by the weight of the column above it, as before, but also by the weight of such a column as is due to a velocity of 4 feet per second, which will be found by calculation to be $\frac{1}{4}$th of a foot high, adding $62\frac{1}{2} \times \frac{1}{4}$, about $15\frac{1}{2}$ lbs. to the load on the valve. This additional load overcomes the leverage of the weight, and closes the valve; but the column of water, 1 foot in area and 4 feet high, contained in C, amounting to 4 cubic feet, is thus arrested whilst moving at the rate of 4 feet per second; and its momentum, which is equivalent to that of $4 \times 4 = 16$ cubic feet, moving at 1 foot per second, or 1 cubic foot at 16 feet per second, must be given out as a force propelling the water along the small pipe at the side. If we suppose that this pipe communicates with a cistern 36 feet high, the velocity due to that height is 48 feet per second; and the momentum of 1 cubic foot, moving at 16

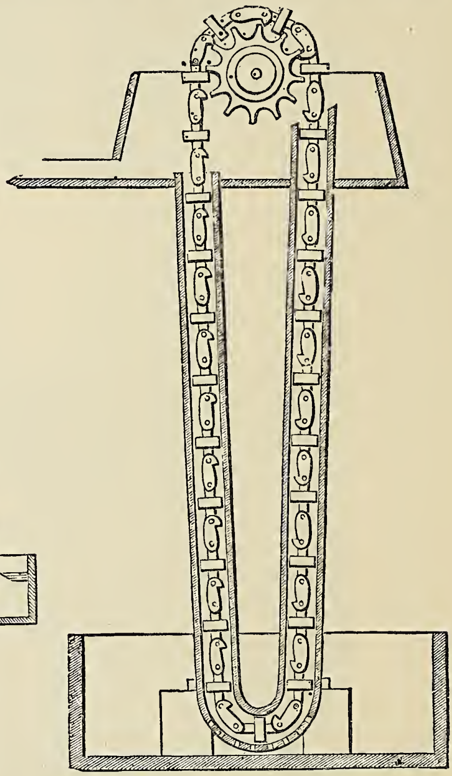


Fig. 223.—Chain Pump.

feet per second, being equivalent to $\frac{1}{3}$rd of a cubic foot moving at 48 feet per second, we should expect that this quantity—$\frac{1}{3}$rd of a cubic foot—would be propelled upwards to the high cistern at each closing of the valve. We must, however, recollect, that the momentum of the larger volume has not only to balance that of the smaller—it must considerably exceed it, because it has to lift the valve, to give the motion upwards to the column, to overcome friction in the pipes and other impediments, and, upon the whole, may be reckoned effective to the extent of not more than $\frac{1}{4}$th of its estimated force. We may estimate, then, that $\frac{1}{12}$th of a cubic foot is propelled up to the high cistern by the descent of 4 cubic feet through 4 feet from

the lower cistern. Should the action not last so long as a second, a smaller volume will descend, and a proportionally smaller quantity will be sent upwards, and conversely; but the number of times the descent and ascent take place in a given period will be greater or less accordingly.

We have presented this calculation only as a rough approximation to the practical results. We are not aware that any carefully-conducted experiments with hydraulic rams have been given to the world, and we therefore do not venture to offer any estimate as a guide for practice; but have merely discussed a case with the view of opening the questions that have to be considered in dealing with such apparatus. In many situations where it may be desirable to raise water for the purpose of ornamental fountains, or of domestic supply, the hydraulic ram is applicable with great advantage. A neighbouring stream may be dammed so as to provide a fall of a few feet, if it have not sufficient local fall naturally; and the apparatus once fixed and properly adjusted, will continue effective for a long period. It is exceedingly simple, entirely self-acting, and seldom liable to derangement, if care be taken to fix gratings on the pipe, so that dirt or extraneous matter of any kind may be prevented from interfering with the action of the valves.

We are indebted to Messrs. Appleby, Engineers, of London, for the following illustration (Fig. 227) and description of a form of Hydraulic ram manufactured by them for use in irrigating land, supplying farm buildings, factories, railways, &c.

"The hydraulic ram was invented by Montgolfier, but since his time has been much improved in detail and construction, and as now made it may fairly claim to be a most efficient and reliable means of supplying water from a running stream to a considerable elevation. It is applicable where no more than 18 inches fall can be obtained, but the greater the fall available the more powerful the action of the machine and the greater the elevation to which the water may be forced. If at all possible a fall of 8 or 10 feet should be obtained. The proportion between the water raised and that running to waste depends mainly on the height of the spring or source of supply above the ram relatively with the height to which the water is delivered. The quantity raised varies in proportion to the height to which it is conveyed with a given fall and the length of the pipe through which the water is forced; the longer the pipe the greater is the friction to be overcome. It is, however, not unusual to apply a ram for forcing water to a distance of 1,000 yards or more. Ten feet fall is sufficient for forcing water to any elevation not exceeding 150 feet above the point where the ram is fixed, and if only a small quantity of water is required and a large quantity is available in the brook or other supply, the water may be raised to a much greater height than 150 feet. It is not advisable to use a greater fall than is absolutely necessary to raise the required quantity of water to the desired height, as the ram is then subjected to an unnecessary amount of work, the wear and tear of all the parts is increased, and the durability of the whole is proportionately decreased. If the ram is fixed at a reasonable distance from the point where the water is to be delivered the fall necessary to deliver a given quantity is approximately as follows. About one-seventh part of the water will be raised to five times the height of the fall which is applied to the ram, or about one-fourteenth part will be raised to ten times the height of the fall, and so on in the same proportion. Thus, if the ram be placed under a head or fall of 10 feet, and the stream delivers 50 gallons per minute, about 7 gallons per minute can be raised to a height of 50 feet, or $3\frac{1}{2}$ gallons to a height of 100 feet; or, in other words, an efficiency of 70 per cent. is obtained. This compares favourably with other forms of pumping machinery, and the rams possess this great advantage, that they can be allowed to work continuously and will require no attention whatever, and beside being very cheap in first cost, they are inexpensive in maintenance. The ram should be fixed in a pit 2 or 3 feet deep, sufficient to protect it from frost, and a race should be cut to convey the waste water away. The pipes should also be laid at such a depth in the ground that they are out of the reach of the severest frost."

We have already given descriptions and illustrations of several varieties of pumping engines employed for the purpose of draining mines. At page 21 will be found an illustration of a Beam Mine-pumping Engine, at page 25 one of an Open Lift Pump for mines; at pp. 47, 48 the Pulsometer has been illustrated and described, followed on p. 48 and 49 with illustration of Messrs. Hathorn Davey & Co.'s Differential Pumping Engine for mining and other purposes.

Of late years steam-pumps of all kinds and power have been largely adopted for raising water, sewage, &c., for draining land, lakes, &c., for irrigation, and a vast variety of other purposes. The different water-works supplying London have some splendid specimens of this kind; in respect to raising sewage the pumps at Barking and Crossness used by the Metropolitan Board of Works to raise the sewage of London, so that it may fall into the Thames, are well worthy of inspection, whether as respects workmanship, power, or efficiency and economy of work. Similar instances in regard to steam-pumps for water-supply may be also found in some of our provincial towns. The following illustrations of steam-pumps, &c., adapted to special purposes, will be a fitting supplement to what we have already given.

Among other ingenious inventions for draining marshy or fenny countries is the *scoop-wheel*. We are indebted to Messrs. Appleby for the following description and illustration of one of these, and also for some general remarks on drainage, generally, of low-lying lands.

" *Scoop-wheels.*—The Upwell, Outwell, Denver, and Welney district, which form a portion of

the 'Fen country' in Norfolk, has for many years past been drained by scoop-wheels driven by windmills ; but as, has already been observed, the results obtained from this kind of motor are not sufficiently reliable, the Commissioners eventually decided to have a new pumping station and scoop-wheel driven by steam-power. The conditions to be fulfilled were stated in the specification issued by the Commissioners, and the design prepared by the Author's firm, and illustrated by Fig. 228, was accepted, and has been successfully carried out.

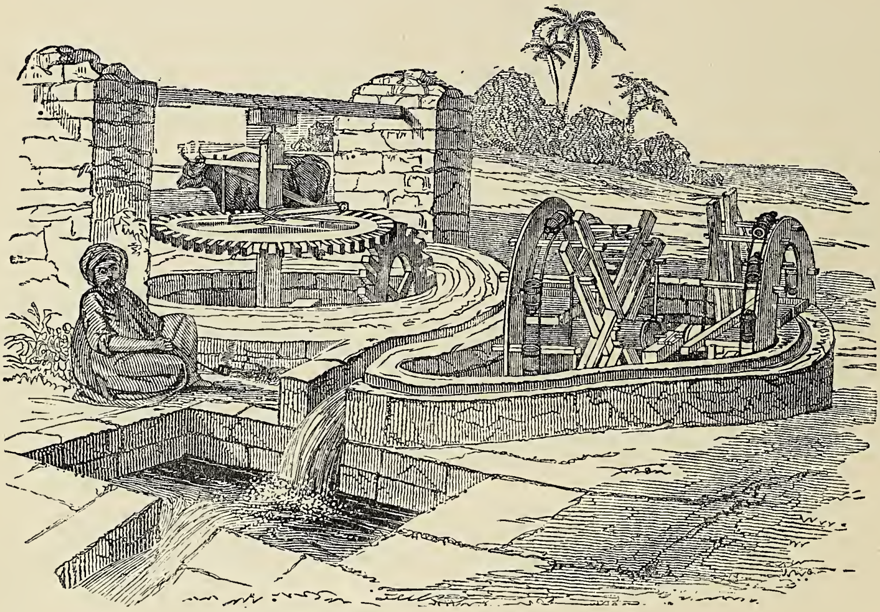


Fig. 224.—Persian Wheel ; employed in Asia for raising water.

"Direct experiment has shown that some of the scoop-wheels now at work do not realize a useful effect of more than twenty-five per cent. of the power expended, but several important improvements have been introduced in the machinery at Upwell. The wheel is capable of delivering 3,500 cubit feet ot water a minute to a height of four feet, or a proportionately smaller quantity to a greater height ; it is constructed as far as possible of wrought iron, and is twenty-four feet in diameter, by four feet wide. The blades are curved in such a manner as to leave

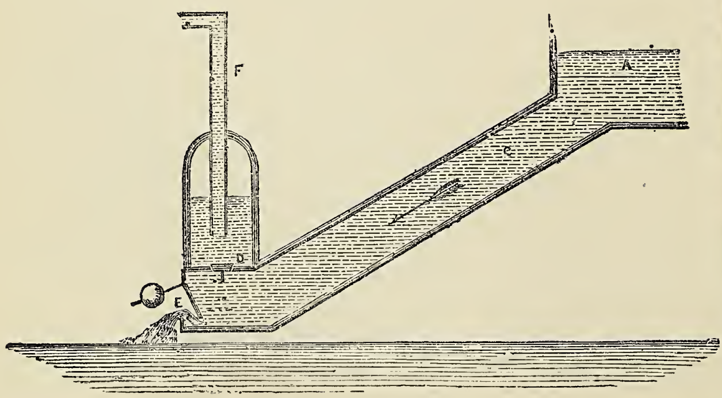


Fig. 225.—The Hydraulic Ram.

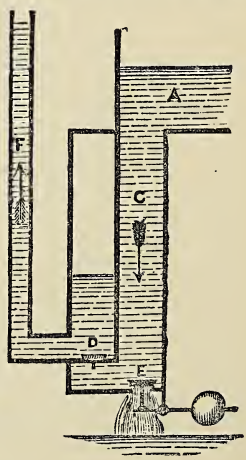


Fig. 226.

the water easily; in many wheels straight boards are used, which lift the water considerable higher than is necessary; the curved blades are ten feet long, and are shrouded by wrought-

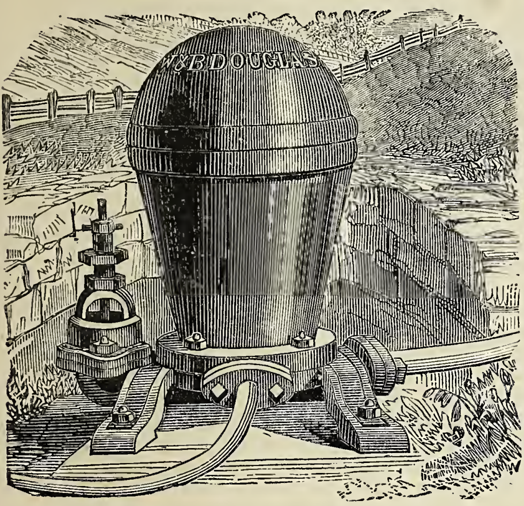


Fig. 227.—The Hydraulic Ram.

iron plates on both sides, the shroudings being carried into the centre. An adjustable curved sluice (as they are sometimes termed) shuttle is provided on the drain or inlet side of the wheel; by this means the volume of water admitted to the wheel is regulated, and is also directed on the blades in such a manner as to prevent any shock from impact. The walls of the culvert in which the scoop-wheel works are curved in to the width of the wheel on both the inlet and outlet side, so that the water runs into and out of the wheel at as nearly as possible the average speed of the blades; this reduces friction and conduces to steadiness in working. The sill over which the water is delivered is gently curved to prevent any unnecessary loss of power. The wheel is hung true, and keyed on to a turned wrought-iron shaft, about nine inches diameter, and this runs in massive pedestals fitted with adjustable gun-metal bearings. To one side of the scoop-wheel is bolted a geared wheel made in segments, about twenty feet diameter, and into this works a pinion on the engine crank-shaft. The engines are of the horizontal high pressure compound condensing type. The high pressure cylinder is ten inches diameter and twenty inches stroke; it is fitted with a Meyer's expansion gear which is capable of adjustment whilst the engine is running, and by means of which the weight of steam consumed can be adjusted exactly to the weight of water and the height through which it has to be raised. The pipe leading the exhaust steam from the high pressure to the low pressure cylinder is made of a very large diameter to act as an intermediate receiver. The low pressure cylinder is arranged and proportioned in such a manner that high pressure steam direct from the boiler can be admitted to it if necessary. The air-pump is in the centre of the condenser chamber, and is placed directly behind the low

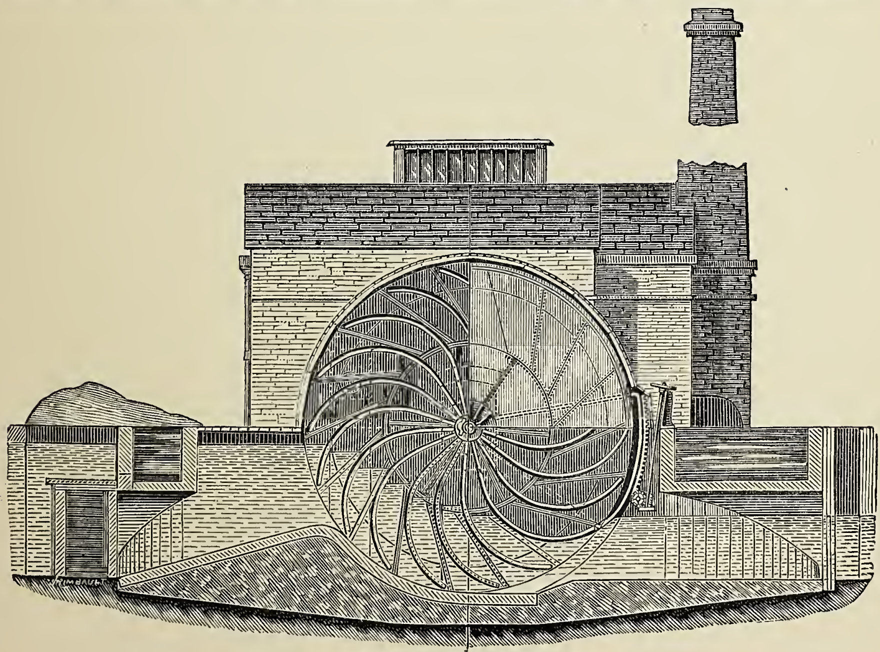


Fig. 228.—Scoop Wheel for Land Drainage.

pressure cylinder on the same bed-plate, the steam and air-pump pistons being coupled to the same rod. The connecting-rods are made of best hammered scrap iron, with adjustable gun-metal bearings at both ends, and are fifty inches (two-and-a-half times the stroke) from centre to centre. There is a feed pump driven from the cross-head of the high pressure engine, but in addition to this a donkey pump is provided for feeding the boilers. The steam pipes and cylinders are all felted and lagged, the high pressure cylinder steam jacketed, and every precaution is taken to prevent waste of fuel. The crank shaft is of wrought-hammered scrap iron, and carries a heavy fly-wheel. The steam for the engines is generated in two Cornish boilers, the internal flues being fitted up with Galloway tubes; the chimney is in brickwork about sixty feet high. The boiler mountings are of the kind used in the best class of work, and include double safety-valves, pressure water-gauges, fusible plugs, &c., and were tested to a pressure of 160 lbs. per square inch, the working pressure being 80. This plant of machinery is compact, the engine and boiler houses are side by side, the middle wall being common to both; whilst the scoop-wheel, although outside the engine-house, is protected by a neat wooden casing. A coal store is built close to the station, capable of holding about sixty tons of coals. The quantity of water and the height to which it has to be lifted varies so much that special designs and estimates are required for each individual district. The cost of the whole of this machinery was £1,700, and the weight was forty-five tons. The cost of the buildings, including chimney, coal store, casing to scoop-wheel, and all foundations, was £700, but this item will vary materially according to the locality, nature of foundation required, &c.

"It is somewhat remarkable that although a large proportion of the Fen country in England, and immense districts in Holland, depend upon scoop wheels for their very existence, but little scientific research has been devoted to improvements in the construction of the wheels and the works connected with them. This may probably, in a great measure, be due to the fact that hitherto windmills have for the most part been the motors employed, and that waste of power has not been so prominently noticeable as it must be when a heavy coal bill has to be paid. Now, however, the use of steam power is greatly increasing, and it becomes necessary to obtain the highest useful effect from the power employed.

"The blades of most wheels have hitherto been straight, pointing towards the centre, or tangental to a small circle. In some wheels of more modern design curved blades have been used, but sufficient care is rarely taken to prevent the shock caused by the too sudden impact of the water on the intake, or what may be called the 'suction' side, nor has sufficient allowance been made for a free flow on the opposite or delivery side. The wheel races are often formed with shoulders, or are suddenly contracted; it is scarcely necessary to point out that these errors in construction are in direct violation of the laws which govern the flow of liquids. In some cases large clearance spaces, varying from one inch to three inches, are allowed on each side of the wheel, and many examples may be seen where the clearance is so great that absolutely no water is delivered until the wheel attains a considerable speed. This is specially observable when the wheel is driven by a windmill running with a light or fitful breeze.

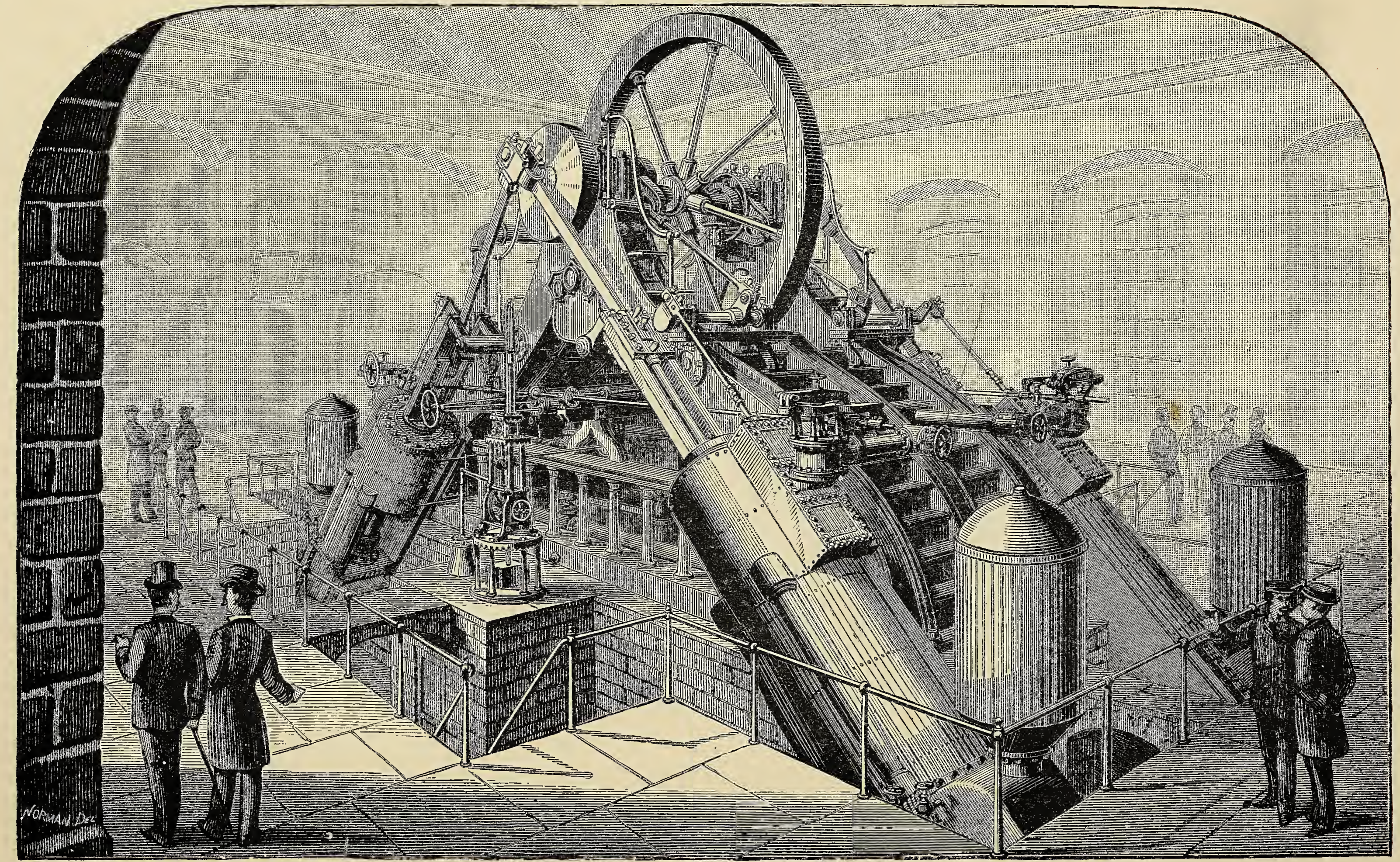
"In other cases no provision is made for shutting off or directing the flow of water on the drain or intake side; the absence of this regulating power throws the whole work on the wheel before it has attained sufficient momentum, and and there is the further disadvantage that it is impossible to adjust the flow of water on the intake side to the height to which it should be delivered, in order to equalise the work and obtain the maximum duty from the power employed. This is a very serious disadvantage when the water raised is discharged into a tidal river, as it often involves the cessation of work during a portion of each tide.

"From the foregoing remarks it will be seen that although the scoop wheel will probably never give very high results in economy of power, it requires less attention than almost any other kind of machinery usually employed for raising water, and may be relied on to deal with the sudden increase due to floods, even after it has been standing for a long period; these are important advantages, and may sometimes outweight the disadvantages in economy of power to which reference has been made.

"In addition to the arrangements of machinery already described as having been successfully employed for the reclamation and drainage of low lands, mention should be made of the very ingenious apparatus designed by the late Sir W. Fairbairn for raising water on low lifts. This apparatus consisted of a wrought-iron trough, about twenty-five feet long by thirty wide, with sides and one end closed; the open end was fitted with a pair of trunnions, having their bearing on the embankment wall of the canal into which the water had to be discharged, the low-water canal being parallel to the high level, directly below the trough. At the closed end there were valves of large area opening upwards in the bottom of the trough, and this end was fitted with trunnions, to which were attached a pair of connecting-rods from the beam of an ordinary single-acting Cornish engine.

"The reciprocations of the beam of the steam-engine were communicated by the connecting-rods to the closed end of the trough or scoop, causing it to dip this end into the low-level drain, the valves above referred to at the same time allowing the water to rush into it until the water level in the trough became the same as that outside. At the upward stroke of the engine beam the valves closed, this end of the trough was raised, and the water was discharged over the embankment.

"A trough of these dimensions was capable of lifting seventeen tons of water per stroke with an engine power of sixty horse, and the duty in water lifted was equal to about three pounds of coal per horse power.



PUMPING-ENGINE AT BUFFALO, U. S. A.

"It will, perhaps, be useful here to record some data as to the engine power required for a given area of land.

"Littleport Fen, near Ely, containing 28,000 acres, was drained by engines of thirty and forty horse-power, and these two engines did the same work, and with more certainty, than it was previously done by upwards of seventy windmills; the cost of maintaining such a number of mills in working order far exceeded the outlay for fuel for the engines.

"Deeping Fen, Lincolnshire, has an area of 25,000 acres, and is drained by two engines of sixty and eighty horse-power.

"Middle Fen, Cambridgeshire, having an area of 7,000 acres, is drained by an engine of sixty horse-power; and many other examples could be given showing about the same average results.

"The rainfall over these districts has been ascertained to average about twenty-six inches per year. Allowing for evaporation and absorption, about eighteen cubic feet of water per superficial yard of ground is the quantity required to be lifted per annum; and assuming that the lift does not exceed ten feet (this figure being in excess of that usual in this country), the best authorities on this subject agree that for moderate areas to be drained, ten horse-power should be provided for each 1,000 acres, and an engine of this power, working twelve hours per day, will do the work in about 140 working days per annum.

"Most of the high-level canals are below high water at the points at which they discharge into the sea, and they are protected by self-acting sluices, whereby the water is discharged at the ebb tide, and as the tide flows the sluice gates close, thus preventing the sea from backing up the water in the canals or drains. A quantity of land in close proximity to the sluices, may thus be drained by gravitation, and some of these works are of a most extensive character; notably that carried out by Rennie in 1821, for the drainage of the Ouse and Nene, whereby 300,000 acres were completely drained, and the low water lines of the rivers reduced several feet. Also that carried out by Messrs. Telford and Rennie in 1829, at the outfall of the Nene, commencing near Wisbeach, and terminating at the Wash. The improvement had the effect of lowering the water mark in the river ten or eleven feet, and bringing 100,000 acres of land into cultivation that were formerly a stagnant marsh.

"In some cases syphons have been introduced for the purpose of carrying the water from the canals into the outfalls; and on the occasion of the blowing-up of the outfall sluice of the Middle Level at Lynn, Sir John Hawkshaw had recourse to this system. The syphons performed the work during the reconstruction of the new sluice in a very satisfactory manner. The new sluice was opened in 1877.

"In designing pumping stations, either for drainage or navigation, it is often necessary very carefully to consider the nature of the strata on which the foundations have to be made, and an error of judgment on this important subject often leads to endless trouble and expense."

Fig. 229 represents a pumping engine suitable for railways, factories, country houses, &c., constructed by Messrs. Appleby. The tank forms the roof of the engine-house; the heat from the boiler and engine, with a chimney passing through a tube, as shown in Fig. 229, is sufficient in England to keep the water from freezing in cold weather. No foundations are required beyond the ordinary walls and floor. This arrangement is low in first cost, and economical in working expenses.

One of the folio illustrations of this work represents a pumping engine at Buffalo, U.S.A. For the engraving and the following description we are indebted to *Engineering*. The report, with matter additional to that we quote, giving trials of the engines, was prepared by Mr. Benjamin, and the pumping engine belongs to the Holly Manufacturing Company of Buffalo:—

"The pumping engine with which the trials were made has four steam cylinders inclined at an angle of 45 deg., and four pumps, one of which is in a direct line with each cylinder. The steam cylinders and their pumps are arranged in pairs on opposite sides of a heavy iron frame, the two cylinders of each pair being connected to a common crank-pin, and the crank for one pair of cylinders being set 135 deg. in advance of that on the opposite side. The engines are of the reciprocating piston form with guides and connecting rods. A connecting rod attached to the back crank-pin actuates an air pump beam giving motion to two single-acting air pumps, and two boiler feed pumps, one of which draws water from the hot well, and the other from the steam jackets which surround the sides of all the steam cylinders. The steam from the jackets passes through a feed water heater, so that the temperature of the feed can be raised to any desired point by increasing the amount of steam supplied to the jackets.

"The connexion of the pumps with the steam cylinders and the steam piston rods with the pumps is by means of keys, so that any engine or pump can be readily thrown out of action.

"Each steam piston is packed by cast-iron rings set out by springs, the set screw of which projects beyond the face of the piston, and there are bonnets in the lower cylinder heads, so that the piston rings can be adjusted without opening the cylinder.

"The pumps are of the piston variety, double-acting, the pump's barrel being secured in a chamber containing the valves by a rib which forms a partition between valves on the opposite ends. The pump valves are flat discs of rubber secured to iron discs having stems working in guides. These iron discs are of sufficient weight to bring the valves to their seats promptly, and no springs are used. The valves seat on metal gratings. The steam and exhaust pipes of the several steam cylinders are so arranged that steam from the boilers can be admitted directly into all the cylinders, and exhausted into the condenser, or live steam can be admitted to but one cylinder, and exhausted into the other three,

then passing to the condenser, thus forming a compound engine at pleasure. To change direct to compound, it is only necessary to manipulate three stop valves, one connecting the steam pipe of three cylinders with the boilers, one connecting the exhaust pipe of the fourth cylinder with the condenser, and the third one connecting the exhaust pipe of one cylinder with the steam pipes of the other three.

thus vary the period of admission from zero to full stroke. The manner in which this cam is moved so as to regulate the speed and power exerted, constitutes the chief peculiarity of the Holly pumping engine.

"The adjustment is effected by means of a regulator connected with the water main, in such a manner that any change in water pressure is immediately corrected by an adjustment

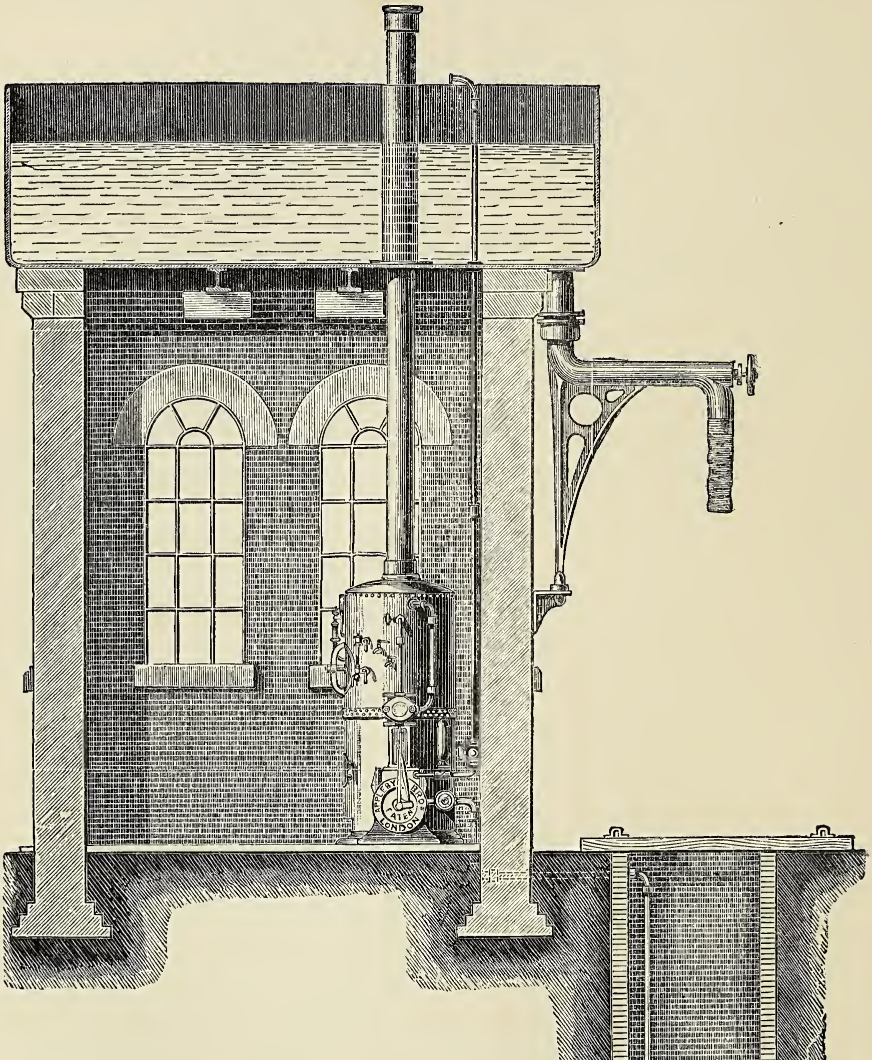


Fig. 229.—Pumping Engine, Tank, &c., for Railway Stations.

"The valve gear of each steam cylinder consists of a slide valve moved by an eccentric in the usual manner, and admitting steam throughout the whole stroke. A double puppet valve, in the steam chest, regulates the point of cutting off, being actuated by a revolving spiral cam, which can be moved in an axial direction, and

of the cut-off, resulting in a practically uniform water pressure under the most varying conditions of supply. If the water pressure tends to fall, owing to an unusual draught upon the main, the cut-off is immediately lengthened, and the engines then exert sufficient power to maintain the original pressure; if the consumption is

suddenly lessened, so that there is a tendency for the water pressure to increase, the cut-off is at once shortened, diminishing the power of the engine sufficiently to maintain the original pressure under the reduced supply; and if all consumption of water suddenly ceases, the engine will immediately stop.

"It is evident from the foregoing description that the Holly regulator acts in an essentially different manner from the ordinary governor, which would increase the cut-off as the water pressure augmented, and shorten the cut-off as the same diminishes. The details of the regulator are briefly as follows:—

"A small water cylinder containing a solid piston is connected directly with the main, and a weight is attached to the piston so as to counterbalance the water pressure. This is effected by suspending the weight from a strap which passes over a cam that rotates as the pressure changes, thus altering the lever arm of the counterbalance, and keeping it in equilibrium with the water pressure, however much the latter may vary. The cut-off cams of the steam cylinders are moved axially either to shorten or lengthen the cut-off when the regulator throws a friction clutch into gear, which it does whenever the water pressure varies from a given amount. A weighted lever would maintain this friction clutch in gear, were it not for the action of the regulator.

"The shaft on which the counter-balance cam rotates has an index wheel, and the index can be set at any desired water pressure. So long as the water pressure varies from the figure at which the index is set, the friction clutch is kept in gear by the weighted lever, and the cut-off is adjusted until the required pressure is reached. At this point the index engages with the weighted lever, and throws the friction clutch out of gear; whenever the water pressure varies the friction clutch is thrown into gear, again changing the cut-off so as to maintain the water pressure constant.

"It will be seen that the cut-off is regulated by positive gear driven by the engine, and the only work required of the regulator is to connect or disconnect this gear. Should this pressure rise very suddenly, however, a piston in a safety cylinder raises a lever to which the cut-off gear is connected, and throws the cut-off to zero instantly if this is requisite.

"A regulator, it is scarcely necessary to add, is an essential feature of a direct pumping system in which the supply is constantly varied.

Principal Dimensions of the Engines.

Steam Cylinders:	
Number	4
Diameter	25 in.
Length of stroke	33 ,,
Diameter of piston rod ..	3·11 ,,
Steam port	11·5 in. by 1·5 in.
Exhaust port	11·5 in. by 2·25 ,,
Length of connecting rod	8·25 ft.
Diameter of shaft	10 in.
,, crosshead pin (steel)	3·875 in.
Dia. of crank-pins (steel)	4·875 in.
Bearing surface of cross-head or guides	130 sq. in.
Air Pumps:	
Diameter	24 in.
Stroke	30 ,,
Number	2
Diameter of Condenser ..	4 ft. 4 in.
Length	29 in.
Dia. of main steam pipe	8 ,,
,, ,, ,, for each engine	5 ,,
Diameter of main exhaust	10 ,,
,, for each engine ..	6 ,,
Flywheel:	
Diameter	12 ft. 4 in.
Width of rim	10·25 in.
Depth	8·5 ,,
Weight	16,000 lb.
Extreme length of engine	43 ft.
,, height ,,	26·75 ft.
,, width ,,	17 ft.
Pump cylinders:	
Number	4
Diameter	15·5 in.
Length of stroke	33 ,,
Diameter of piston rod ..	2·86 in.
Displacement of all pumps per revolution	212 U.S. gals.
Number of valves, suction and discharge at each end	6
Area of opening, suction, and discharge at each end	147·96 sq. in.
Diameter of main suction and discharge pipes ..	24 in.
Diameter of main suction and discharge pipes at each end of pump ..	14 ,,
Length of service pipe into which pumps deliver water 36 miles, ranging in diameter from	24 in. to 4 in.
Number of discharge air vessels	4
Internal diameter of discharge air vessels	22 in.
Number of suction air vessels	4
Internal diameter of suction air vessels	24 in.
Internal height of suction air vessels (flat tops) ..	36 ,,

Boilers.—Two boilers were used to supply steam to the engines during the duty trial. They were internally fired, flue and return tubular. The only protection against loss from radiation was the casing of light iron, a few inches away from the shells, and during the run some hair felting one inch in thickness was laid loosely over some of the most exposed portions of the casing.

The boilers were provided with steam domes, from which the steam was supplied to the engines. The following are the principal dimensions:—

Principal Dimensions of the Boilers.

Diameter of shell	6 ft.
Length of boiler	13.88 ft.
Number of flues in each boiler	3
Internal diameter of flues	1 16·75 in. 2 11·5 „
Length of flues	4.65 ft.
Number of return tubes in each boiler	86
Outside diameter of tubes	3 in.
Length of tubes	11·95 ft.
Total grate surface	42·68 sq. ft.
Heating Surface.	
Tubes	1608·3 „
Furnaces	141 „
Flues and connections ..	127·7 „
Total..	1977 „
Cross sections of flues ..	5·8 „
„ „ tubes ..	7·3 „
Ratios.	
Heating to grate surface	46·1
Cross section of flues to grate surface	0·136
Cross section of tubes to grate surface	0·17
Height of chimney above grate	76 ft.

Centrifugal pumps have of late years been largely adopted for raising water under certain conditions. The limit at which they can be economically used depends upon circumstances which are constantly varying. Mr. Appleby considers that it might be as much as forty or fifty feet, but may be fixed under ordinary conditions at or below twenty-five feet from the level of the water at the suction to the point of discharge. They are invaluable for raising a large volume of water to a moderate height, and are of great use for raising liquids containing a large mixture of foreign matters, such as are found in bleach and dye works, tanneries, paper-mills, &c.

One of these pumps is represented in Fig. 230. We are indebted to *Engineering* for the illustration and description.

"The engraving represents one of a pair of direct-acting centrifugal pumping engines, constructed by Messrs. Gwynne and Co., Essex-street Works, London, each of these engines being capable of raising 100 tons of water per minute, to an elevation of 17 feet high. The engines are fitted with cylinders 27 inches in diameter by 20 inches stroke, and work at the rate of 100 revolutions per minute. The steam in the boiler is supplied at 75 lb. per square inch, cut off at about one-eighth of the stroke by adjustable expansion valves. The cylinders are steam-jacketed all round, the jackets being supplied with steam direct from boiler. Four smaller sets of similar pumps to that we illustrate were erected by Messrs. Gwynne and Co. some time ago, these smaller engines, according to contract, having to discharge 72 tons per minute, 3 metres high, with an hourly consumption of 3 kilogrammes, or 6·6 lb. of coal per horse power in water lift. When the trials were made it was found that each pump discharged 88 tons per minute, while going at 100 revolutions per minute, while the hourly consumption was only 2·7 kilogrammes, or 5·94 lb. of coal per horse power in water lift. The engines now illustrated are expected to yield even better duty than the four mentioned above. They have an ordinary ram condenser with valves for large outlet. A large air pump is provided for charging the centrifugal pumps which have no foot valves, but in case of accident to air pump the condenser itself is capable of charging the pump by an arrangement between the centrifugal pump and condenser. The whole of the machinery is made in only three pieces, all securely bolted together; this is specially necessary with such foundations as are found in the low lands, where drainage operations are being carried out. In conclusion, we may remark that the particular engine illustrated, which we had an opportunity of examining a short time ago, was an admirable specimen of highly finished workmanship most creditable to its makers."

Fire-engines.—In the days when houses were more frequently built of wood then they are at present, fires were more likely to occur; but there do not appear to have been, until comparatively modern times, any regular and systematic means of extinguishing them. The first improvement, in England, upon the use of a mere bucket to throw water on a burning house, was the adoption of a kind of squirt or syringe ; numbers of which were kept by the parochial authorities, in the same way as fire-engines afterwards were. Each of these squirts was about three feet in length, with an aperture at the lower end about half an inch in diameter, and a capacity of about half a gallon. It had a handle on each side, and was worked by three men, of whom two held the squirt by the handles and the nozzle, while the third worked a piston within it in the manner of a syringe : the aperture was held downwards in a vessel of water while the squirt was being filled ; and, when filled, the nozzle was directed upwards, and the stream of water directed on the burning materials by the working of the piston.

Germany seems to have been the country where fire-engines, such as we generally understand the term, were first introduced. An inhabitant of Nuremburg, named, Hautsch, constructed in 1567 a machine, consisting of a water-cistern, seven or eight feet long, drawn on a kind of sledge ; it had arms or levers worked by twenty or thirty men, whose exertions propelled from the machine a stream of water an inch in diameter, and, as it is said, to a height of eighty feet. By about the year 1672, the engines had received considerable improvements, chiefly from the ingenuity of two brothers, named Vander Heyden. These persons were inspectors of apparatus for extinguishing fires at Amsterdam, and invented the flexible hose or pipes, which have ever since formed part of the fittings of a fire-engine. These flexible pipes enabled the stream of water to be carried in

various directions, and thus brought to bear on parts of the burning mass which could not otherwise be reached. Fig. 231 is copied from an old print, the inscription under which seems to show that the fire-engine here sketched (or rather one of them, for there appears to be one on a different construction in the background) was the kind first employed in Holland.

Some of these German or Dutch engines were probably brought into England, and were gradually improved upon, till they have at length reached their present effective state. In the common form of engines (Fig. 233) there is an oblong box or cistern for containing the water, a pipe to admit it, handles to work the engine, and an upright chest or chamber, the use of which is better shown by the section in Fig. 234. There is an upright air-chamber with various pipes and channels of communication, so planned as to cause the air confined within the upper part of the chamber to press on the water beneath it, and thus to force out the latter with more regularity than would be attained if there were no air-chamber of this kind, as already explained in our remarks on force pumps at page 270 *ante*.

For the following remarks on steam fire-engines we are indebted to Mr. C. J. Appleby, quoted from Messrs. Appleby's "Handbook of Machinery." We are also indebted to that firm for some of the illustrations which follow.

"In 1830 Braithwaite constructed the first land steam fire-engine that was used in London; he made several which were exhibited at various public trials, but could not succeed in bringing them into general use.

"The next attempt to apply steam for the working of fire engines was made for the London Fire-Engine Establishment, which was not instituted till some time after Braithwaite's endeavour to introduce steam fire-engines. In 1852 they had one of their large hand-worked floating fire-engines altered so as to work by steam instead of manual power. The engine having been constructed by Tilley, the alterations were entrusted to and carried out by his successors, Shand, Mason, and Co.

"In the same year the first American land steam fire-engine was constructed in New York.

"The success which attended the above-mentioned alteration, and the great advantage which resulted from working by steam instead of manual power, induced the London Fire Engine Establishment to have an entirely new floating steam fire-engine constructed for them, and in 1855 they invited tenders with designs. The experience gained by the above-mentioned alterations enabled the contractors to compete successfully on this occasion, and their design was adopted.

"It consists of two distinct direct-acting engines and pumps placed horizontally one on each side of the boat, with a boiler to each, so arranged that each boiler will work either or both engines if required. The pumps are readily disconnected from the steam engine, which also works one of Appold's centrifugal pumps for propelling the vessel by the ejection of water from the sides, either towards the head or stern, by means of valves which work independent of each other on each side of the vessel. There are four outlets on the deck of the vessel to which the hose is attached. It will throw 2,000 gallons of water per minute to a height of 160 feet.

"The same manufacturers have also constructed one for the Council of India, for use on the river Hooghley, at Calcutta, capable of delivering 3,000 gallons of water per minute. The engines, when disconnected from the pumps, work the screw propeller, with which the vessel attains a speed of 13 miles an hour.

In 1858 the same makers completed the first land steam fire-engine which had been made since Braithwaite's, which was tried several times in public in London, and afterwards sold and sent to St. Petersburgh; they also constructed two more in the following year, one of which the London Fire Engine Establishment took on hire in 1860 for one year; this proved so advantageous that they purchased the fourth engine made by the same firm. This, with one of the two made in 1859, were the only land steam fire-engines at the great fire in Tooley Street in 1861.

At the Great Exhibition, 1862, there was a steam fire engine exhibited by a manufacturer in New York, which was worked publicly at Messrs. Hodge's Distillery at Lambeth. Messrs. Merryweather & Son placed their first steam fire-engine in the Exhibition in 1862, which, like the one exhibited by Shand & Mason, was not in time from the opening, and consequently neither of these were eligible to compete for prizes.

The last inquiry on fire-engines was conducted under the auspices of a Parliamentary committee, and some interesting and important facts were elicited from experiments made at the South Essex Waterworks in June, 1877. It had been suggested that the Metropolitan District should be supplied with fixed hydrants to enable fires to be extinguished by affixing hose to these hydrants playing directly on the flames without the intervention of fire-engines; the experiments were carried out to determine how far the pressure in the water mains was suitable for this system. The series of elaborate and conclusive experiments then made showed that in overcoming the friction due to driving 600 gallons per minute through 220 yards of 4-inch pipe, the pressure required was equal to a head of 225 feet. To further deliver these 600 gallons through 4 jets, each with 200 feet of hose, another 55 feet head would be required; and to throw the water a height of 50 feet from the jets required a further head of 80 feet. Therefore to deliver those quantities above-named through the lengths of pipe and hose would require no less a head than 355 feet; and it is needless to say that such a pressure is not at present obtainable in London. It is true that 220 yards is a great length of pipe for so large a quantity of water, and that with a larger and shorter pipe a much less pressure would be required. Nevertheless, when we consider that

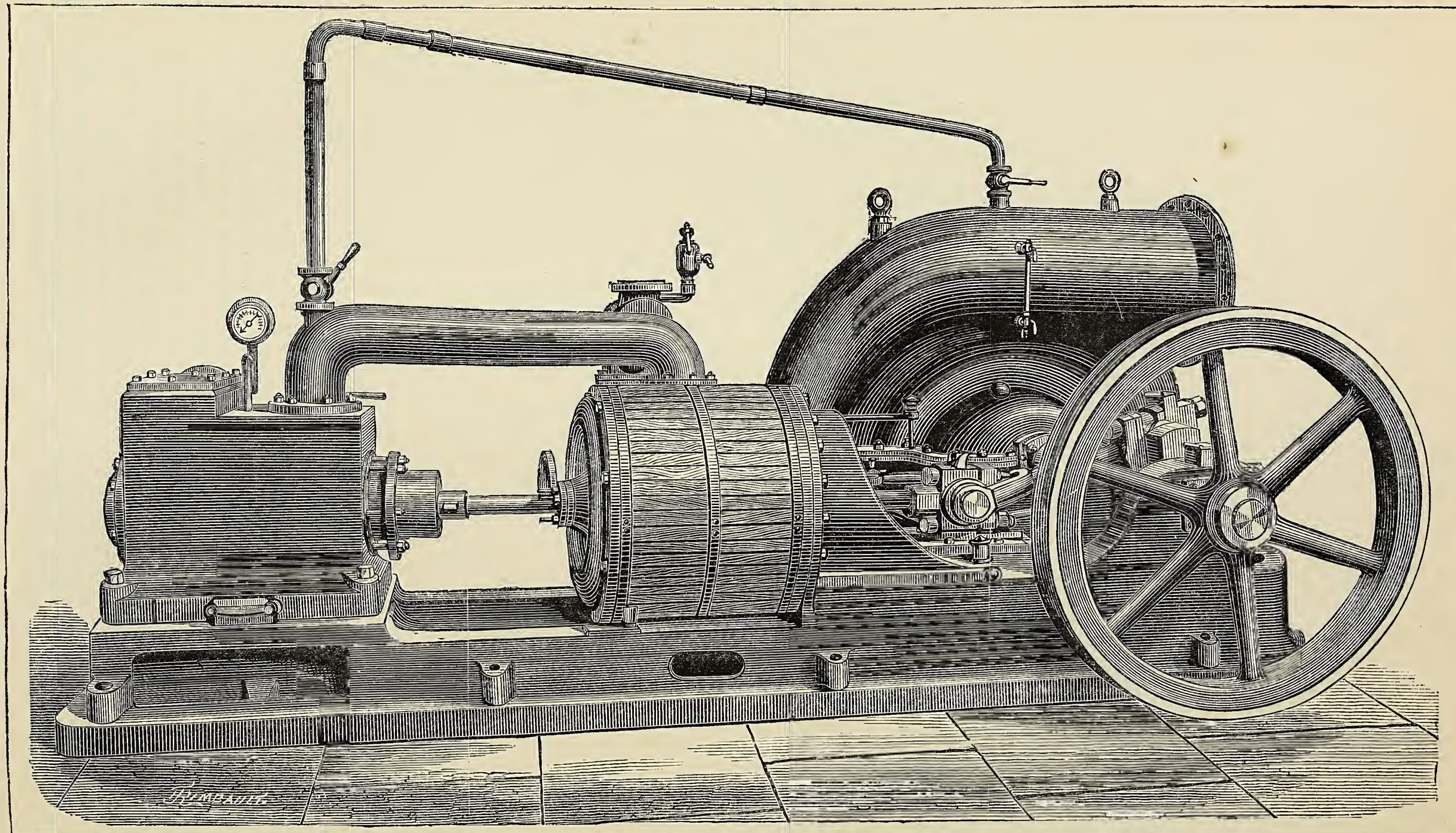


Fig. 230.—Steam Centrifugal Pumping Engine.

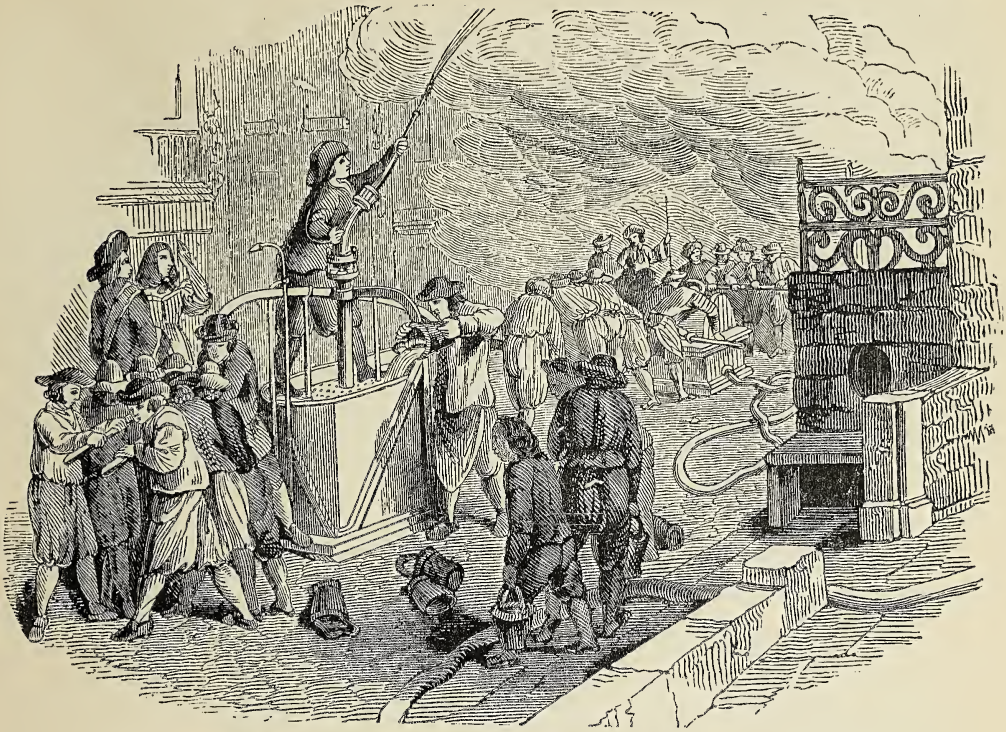


Fig. 231.—The First Fire-engine; used in Holland about 1660.

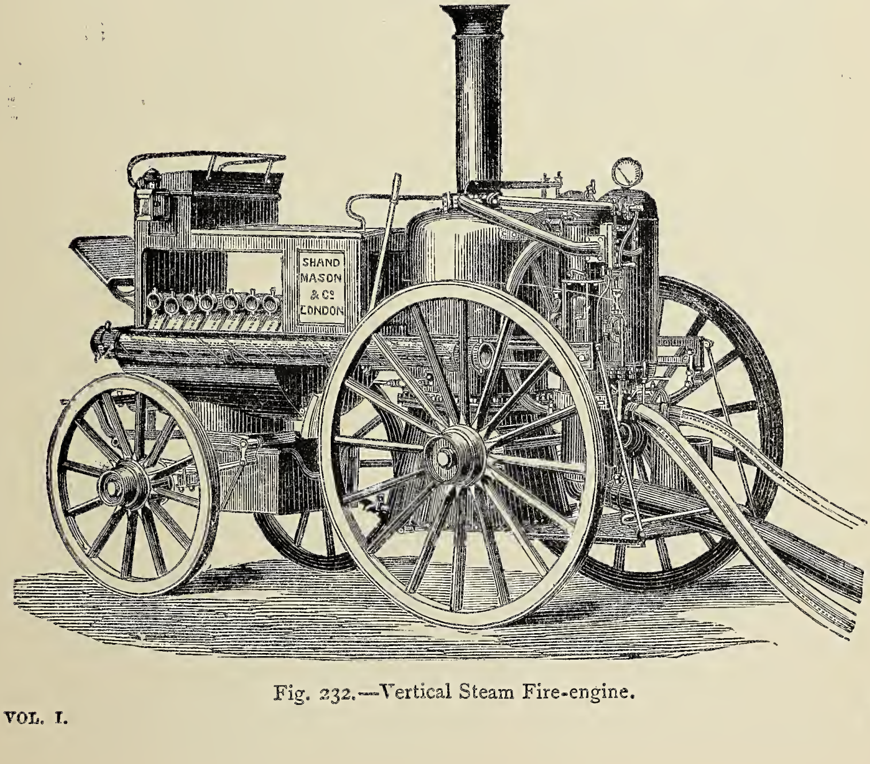


Fig. 232.—Vertical Steam Fire-engine.

if high pressure were introduced in the metropolis, all the existing house pipes and fittings would have to be replaced or strengthened, at a probable cost of about four millions sterling, in addition to the cost of street hydrants estimated at three-quarters of a million, it is probably that it will be a long time before fire-engines are superseded by hydrants.''

In the city of London, hydrants have been largely introduced in the main streets during the last few years.

" *Vertical Fire-Engines* of the type Fig. 232 are extensively used by the London and other Fire Brigades. There is only one steam and one water cylinder, and the construction is extremely simple in arrangement and detail. This engine was first publicly tested at the trials held at the Crystal Palace in June, 1863, when it delivered one-half more water in proportion to its weight than any other engine exhibited, and whole engine is mounted on a strong wrought-iron frame, with forelocking gear, springs, four high wheels, pole and sway bars for a pair of horses, driving seat and foot board. The engine is free from all peculiarities with which engineers are not familiar, so that if anything requires adjustment or repair it can be done by any engineer, and a man of ordinary intelligence can work it after a few trials. The whole of the parts are readily accessible, and the hose and suction pipes are clear of all the machinery when in action. The engine will deliver through two lines of hose, which may be used separately or together by means of a valve so arranged that both outlets cannot be closed at the same time. As an instance of the greatly diminished cost of working fire-engines as compared with the old hand-work engines, at the large fire at Beale's Wharf in Tooley Street, which occurred some years ago, eight steam fire-engines threw

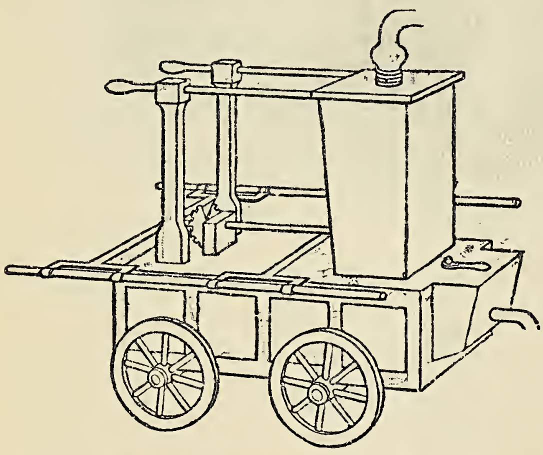


Fig. 233.—Fire-engine.

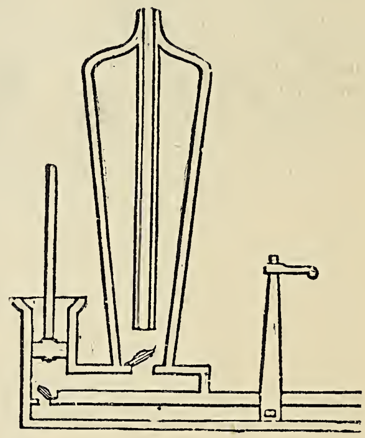
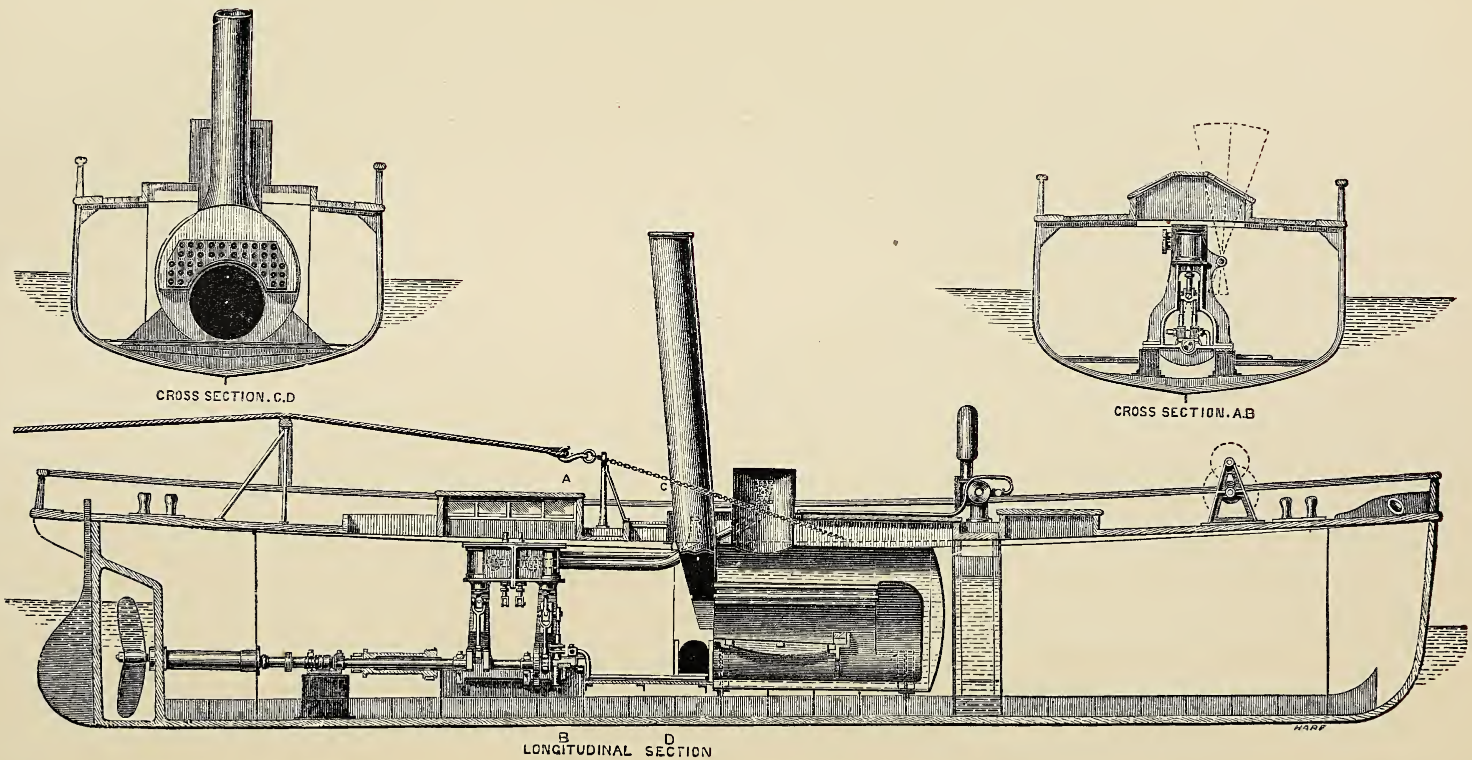


Fig. 234.—Mechanism of Fire-engine.

was awarded the first prize of £250. Since that date, prizes have been awarded for engines of this design at Middelburg (in Holland), Cologne, Dublin, Paris, Altona (Hamburg), and other places. The boiler is of the vertical tubular description, fitted with all necessary mountings, including safety valves, gauges, &c. Steam of good working pressure (about 100 lbs. per square inch) can be obtained from cold water in less than ten minutes from lighting the fire. The steam cylinder is directly over the pump, which is of the bucket and plunger type, and both are firmly attached to the boiler. The pistons of the steam engine and pump are directly connected by two rods, and the length of the stroke is limited by means of a crank shaft; after many years' experience this is found to be the best arrangement, as it not only prevents damage arising to the cylinder covers, but allows of the adoption of a very simple valve motion. The crank shaft carries a fly-wheel which enables the engine to be pulled round for oiling, &c., when it has not to be used for some time. The feed-pump is driven from the crank shaft. The 6,000 tons of water at an expense of £5 5*s.*; to do the same work in the same time, eighty manuals would be required at an expense of £600.''

There are many modifications of this class of fire-engine made according to the views of the inventors, and adapted to special requirements.

" *The London Brigade Manual Fire Engine.*—Fig. 235, is a very complete hand-worked fire engine, and is especially adapted for municipal, country, volunteer, and private fire brigades; it is light, yet strongly built. The works are of the best description, being fitted with metallic valves, two gun-metal cylinders and pistons, copper suction and delivery air-vessels, and are fixed in a strong well-seasoned oak cistern, with side pockets to carry suction and branch pipes, and a box placed over the cistern to carry hose and implements, with driving-seat and footboard-wrought-iron forelocking carriage and drag handle, with pole and sway bar for a pair of horses, springs and high wood-spoke wheels for rapid travelling, draws water either through suction-pipe from ponds, rivers, &c., or from



STEAM SCREW TUG, WITH HOIST AND FIRE ENGINE.

cistern of the engine, &c., and delivers on either or both sides. Each engine is provided with a copper branch pipe, having gun-metal screw to attach to hose, and boss to take jet pipes, a copper strainer with gun-metal screw to fix on end of suction-pipe, a wrench for suction air-vessels, two hose wrenches, and a screw-driver with shifting handle.

These engines are adopted by the Metropolitan Board of Works, the Volunteer Brigades in the neighbourhood of London, and almost all the large towns and districts in England, the various Insurance Offices, Her Majesty's War Department, Admiralty, Council of India, the Colonies, and in many foreign countries.

Floating fire-engines are now largely adopted for the protection of docks, warehouses, shipping, &c., where an abundant supply of water can be obtained, in which to float the engine, &c. Formerly these were anchored at any convenient station, but had to be towed by a tug, or otherwise removed to the neighbourhood of the fire. Fig. 236 represents one of these at anchor waiting for a "call." But frequently it happened that much time was occupied in moving the vessel, and consequently the value of the arrangement was greatly lessened. Of recent years, however, this difficulty has been overcome. Messrs. Appleby describe a form of light draught high-speed floating steam fire-engine as follows :—

"*Light-draught High-speed Floating Steam Fire-Engine.*—Figs 237 and 238 were specially designed for the Associated (London) Insurance Companies, for use in the shallow part of the Thames. The vessel is forty feet long by ten feet wide, draught under two feet at stern and one-and-a-half feet forward, and is of great strength, having two bulkheads and a continuous deck. There is a roomy cabin with lockers on each side, and hose reel for twenty forty feet lengths of leather hose. The engine has three cylinders arranged to drive both the fire pump and the propellers. There are twin screw propellers driven by bevel gearing arranged with double pinions and clutches, so that the propellers can be made to revolve in either direction, and by this means the boat is very quickly steered. An arrangement is provided by which water jets from the fire pumps can be made to assist the propellers when it is desirable to travel at the maximum speed, this apparatus being under the control of the steersman. The pumps are capable of delivering 670 gallons per minute to the height of 185 feet."

One of the folio plates illustrated in this work, represents a Steam Screw Tug, with Hoist and Fire Engine, constructed by Messrs. Appleby, to whom we are indebted for the illustration and the following description :—

"*Steam Screw Tug with Hoist and Fire Engine.*—The plate illustrates a steam tug which serves many purposes, and is worthy of special notice. The total length of the vessel illustrated is forty-five feet, the extreme breadth ten feet, and the depth seven feet ; and as it was for use abroad, it was constructed to be sent out in sections, and easily fitted together on arrival at its destination. The tug is capable of towing two lighters, each carrying fifty tons, and (by means of the hoist shown in the crankshaft) discharging the cargoes into vessels lying out in the roads. The boiler is of the type generally employed for marine work, and occupies the centre portion of the boat; it is five feet in diameter, and five feet long, and has thirty-eight return tubes two-and-a-quarter inches diameter. The engines are of the inverted kind, and are placed aft of the boiler, the crank shaft being coupled directly to the screw shaft. The cylinders are eight inches diameter, and eight inches stroke. The valves are placed between the cylinders, and are fitted with link reversing motion ; the crank shaft, piston rods, and cross heads, are all made of steel, the eccentric straps, glands, pump plungers, &c., of gun-metal, and the link motions are case-hardened. The screw is of cast iron, four feet in diameter, and has four blades four-and-a-half feet pitch. The screw shaft is of steel with the thrust collars forged on, and a thrust bearing is provided as shown in the engraving. On the crank shaft between the thrust bearing and the engines is fitted a direct acting hoisting barrel similar to that employed in the steam warehouse hoist illustrated in another folio plate to be afterwards described. This hoist has a simple arrangement for obtaining either single or double purchase; it can be used for a variety of purposes, such as discharging ships' cargoes into lighters or *vice versâ*, and is altogether a very valuable addition to a tug. On the forward side of the boiler is fixed a large water tank, one side of which is formed by a bulkhead ; this tank can either be stored with fresh water for use in the tug's own boiler, which is much better than employing salt water, or it can be used for taking a supply of fresh water out to ships in need of it. Over the tank will be seen a direct-acting steam fire-engine ; this is a very important addition to the tug, as in case of a fire breaking out on the quay, or in the harbour where the tug is usually employed, it can be immediately used as a floating fire-engine. The pump is also used for pumping fresh water into ships. The arrangement of the towing gear is so clearly shown on the engraving that it needs no special description. All the pipes connecting the engine and boiler, &c., are of copper, and the whole is of the best workmanship and materials throughout.

"The tug referred to was designed and supplied by the Authors for use on the coast of Africa, and it has rendered good service under the conditions above referred to. Everything was fitted together in place, and marked for re-erection at destination, but it was sent out in pieces, which effected a large saving in freight ; the sides of the hull were painted different colours, and the plates and ribs being distinctly marked, the work of erection was completed very quickly, and at little cost, by men who had not previously been employed in work of that character."

Hydraulic Lifts, Cranes, Jacks, Presses, &c.—Of recent years water has been largely employed for a great variety of purposes, that were for-

merly not thought of. Being all but incompressible it is a convenient mode of conveying power to a distance, and, in many cases, of exercising force or power, directly for a great variety of purposes.

The hydraulic lift and the hydraulic crane neck of the cylinder, so as to prevent the escape of water around the plunger. A pipe from a high cistern conducts water into the cylinder, and another pipe permits the water to issue from it. Each of these pipes is provided with a stop-cock, so that the water may be admitted

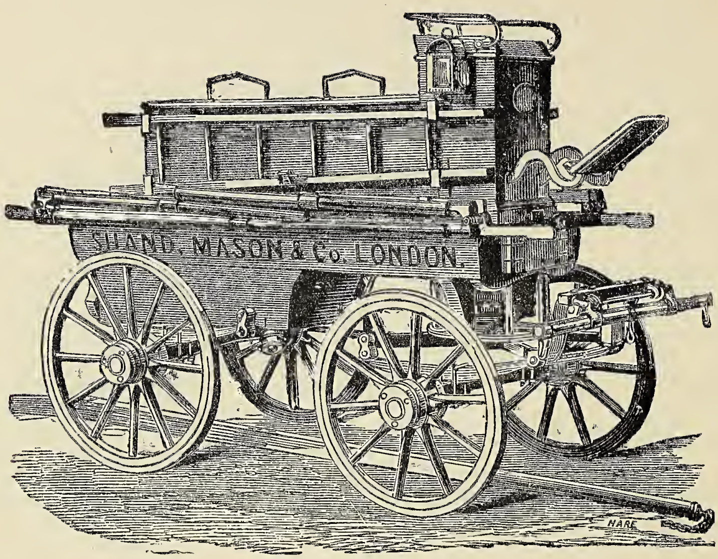


Fig. 235.—Manual Fire-engine.

may be first noticed. The hydraulic lift, in its most simple form, consists of a cylinder closed at bottom, and fitted with a plunger or ram, which passes through the top and supports a stage (Fig. 239). A leather collar, fitting round the plunger, is placed in a recess provided in the to the cylinder, or allowed to flow from it at pleasure. Since liquids communicate pressure equally in all directions, every part of the cylinder and the plunger is pressed upon, by a force proportioned to the height of the cistern which supplies the apparatus. Every 27 inches

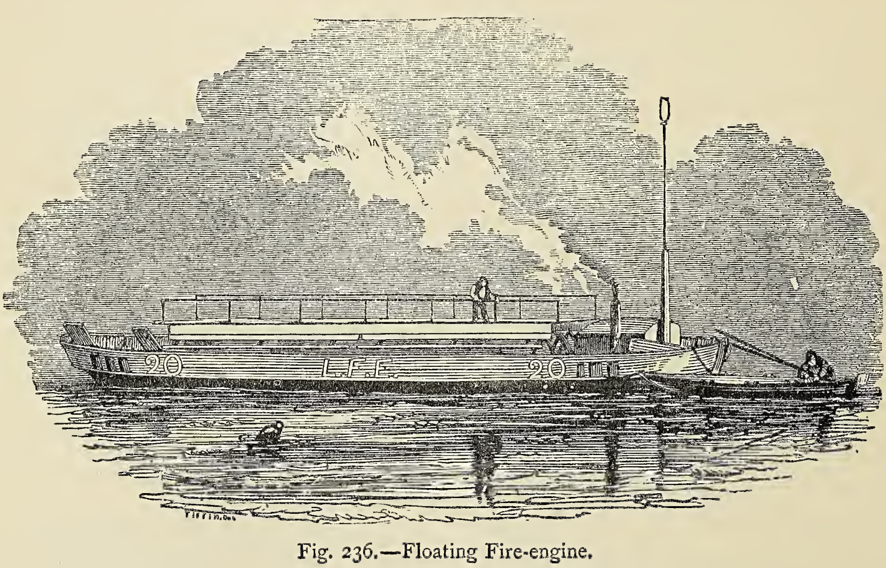
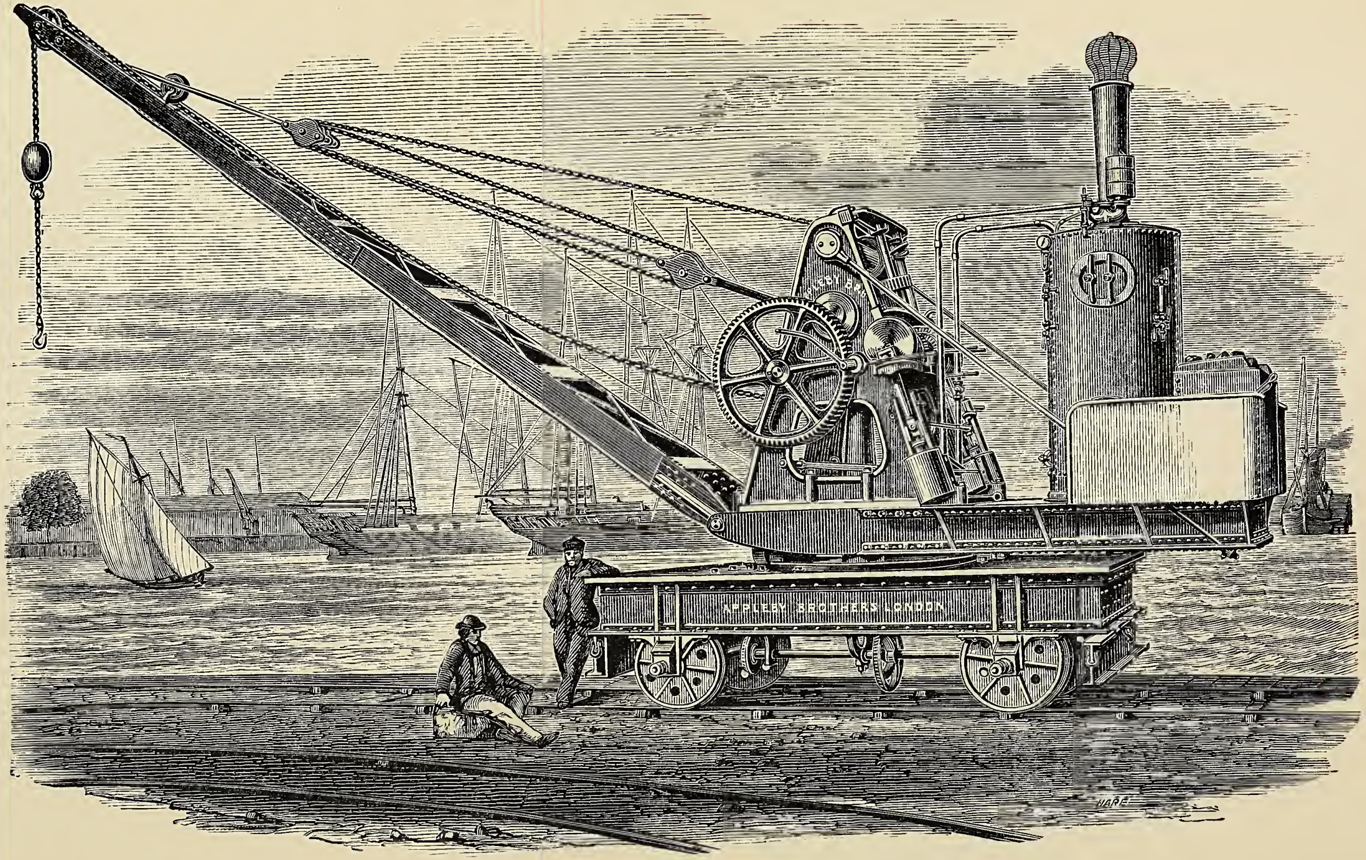
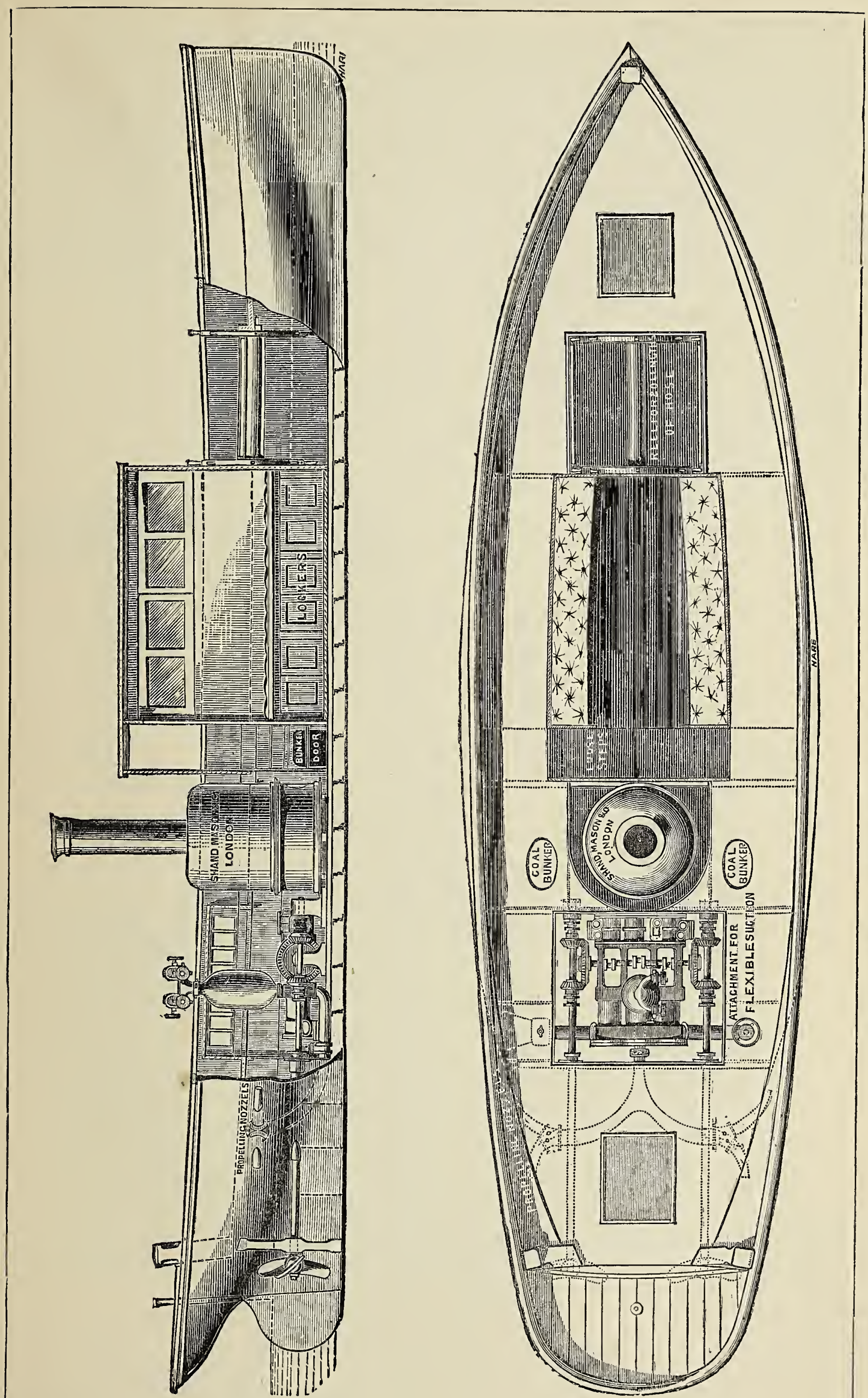


Fig. 236.—Floating Fire-engine.



TEN-TON LOCOMOTIVE STEAM CRANE



Figs. 237 and 238.—Light-draught High-Speed Floating Steam Fire-engine.

of height produces a pressure of 1 lb. on every square inch of surface exposed to it; and by making the area of the bottom of the plunger sufficiently large, a considerable weight can be raised on the stage which it carries. Thus, if the cistern at the top of a house be 54 feet above the ground-floor, the pressure on the internal surface of any vessel on the ground-floor, connected with it by a pipe, is 24 lbs. per square inch. If this vessel be a cylinder such as we have described, fitted with a plunger 10 inches diameter, having therefore a sectional area of $78\frac{1}{2}$ square inches, the pressure forcing

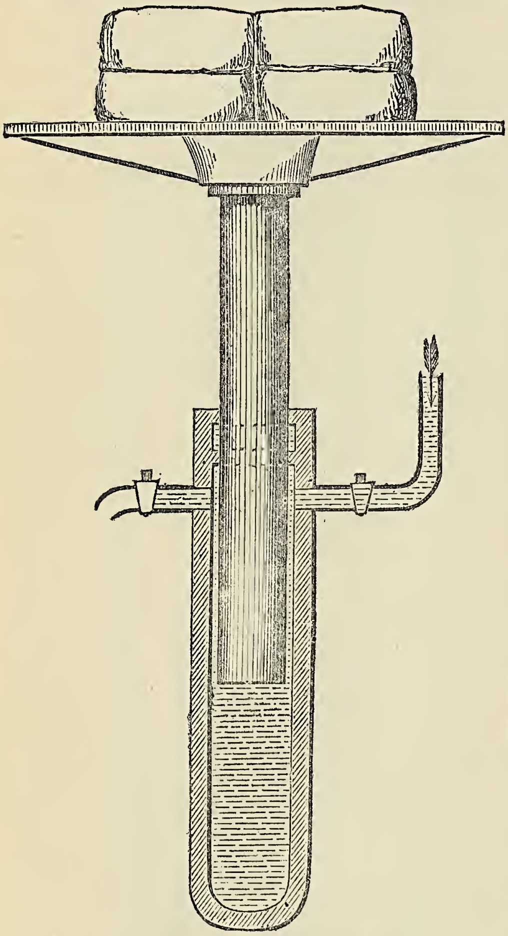


Fig. 239.—The Hydraulic Lift.

this plunger upwards amounts to $78\frac{1}{2} \times 24 =$ 1,884 lbs., and if from this we deduct 764 lbs. as a weight, including that of the plunger and platform, there remains a pressure of 1,120 lbs. forcing the plunger upwards. A load then of this amount, half a ton, may be placed on the platform when it is in its lowest position, and the cock being opened to the cistern, the whole will be raised to a height equal to that of the plunger, which may be made sufficient for lifting goods from one floor to another. By closing the cistern-cock and opening the other the water is permitted to leave the cylinder; and the plunger, no longer subjected to upward pressure, descends to its former position.

The water pressure may be made to act in a way somewhat different in detail, but similar in principle, by fitting the cylinder with a piston, connected br a rod passing tightly through the cylinder cover with a rope or chain, which may be led by pulleys in any convenient direction for lifting weights attached to it. The water-pressure acting on the piston, forces it down the cylinder, and thus pulls the chain and lifts the

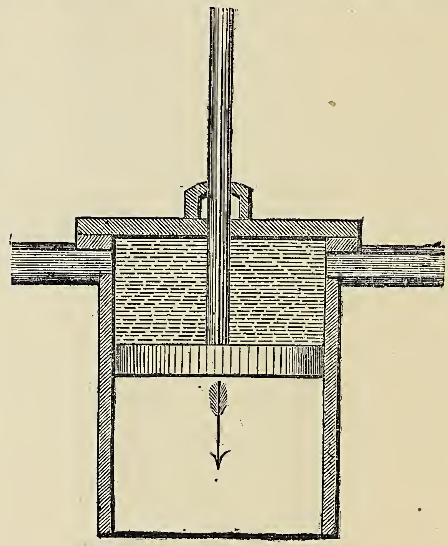
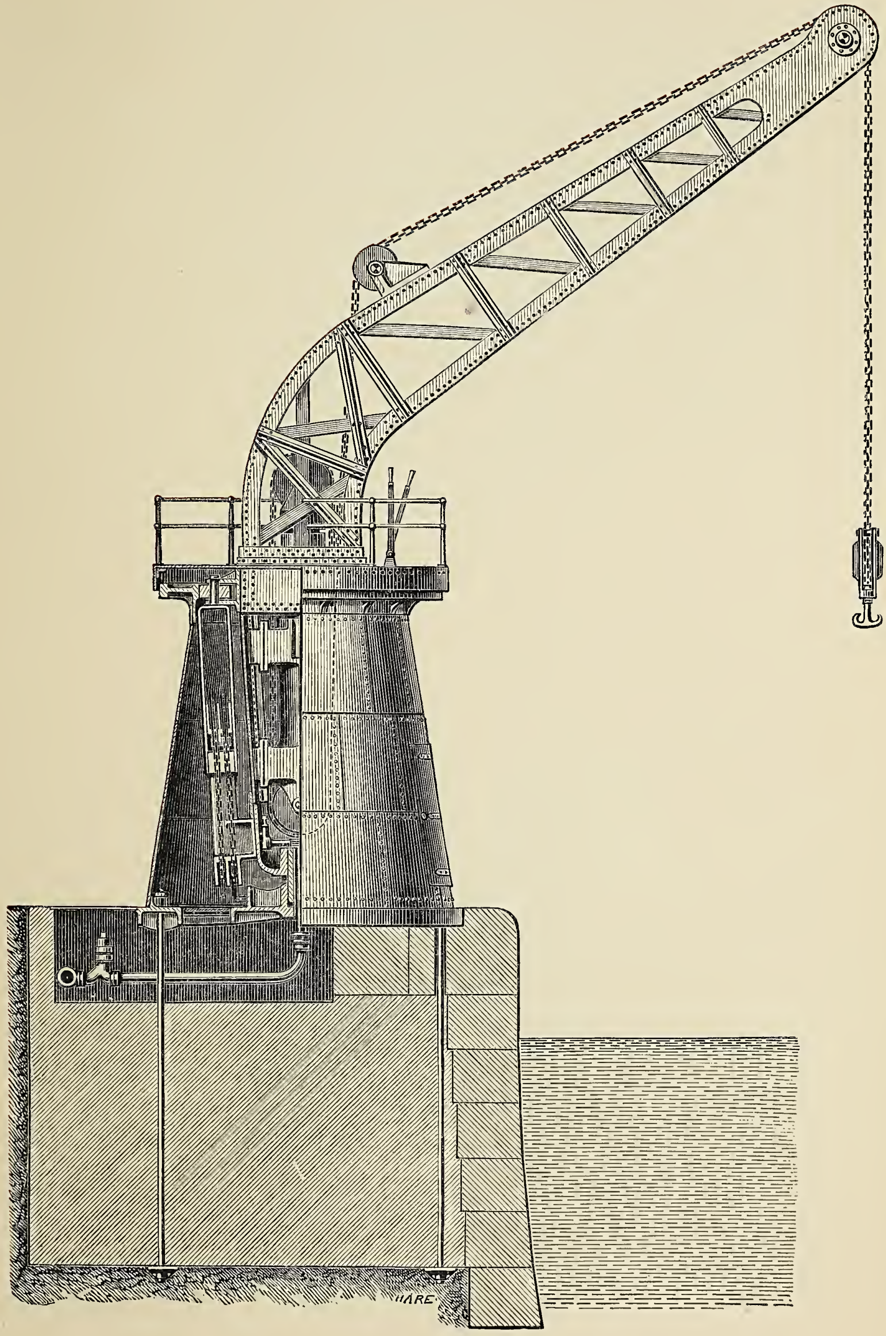


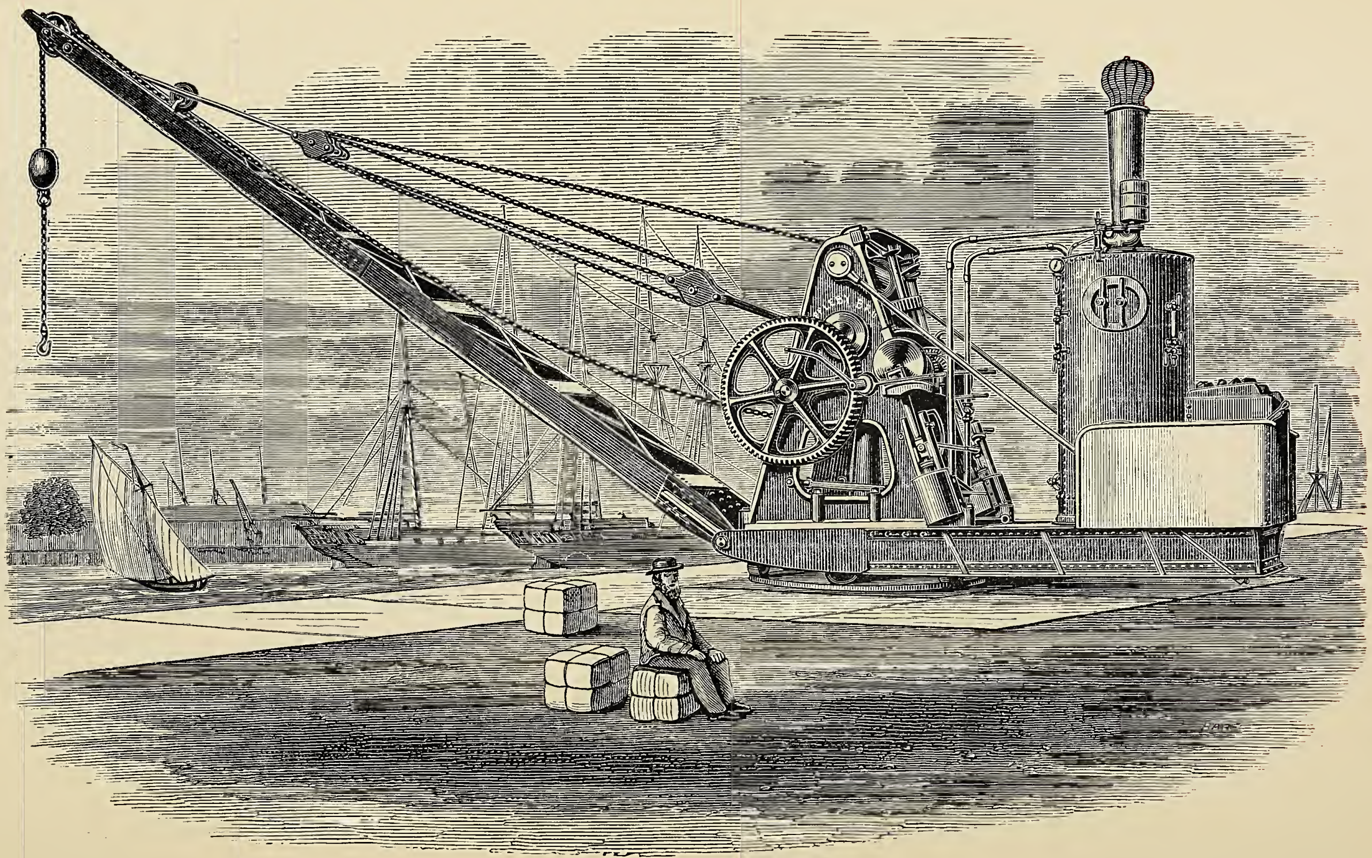
Fig. 240.—Section of the working parts of a Hydraulic Crane.

weight. Such an arrangement constitutes the Hydraulic Crane. The advantage of employing water for lifting weights in this manner consists in the circumstance that a small steam-engine, or other power, can be constantly employed in raising the water to a high cistern, and that great lifting power can be obtained for a short time by the expenditure of a portion of the water thus raised. The water lifted to a height, becomes, in fact, a reservoir of power, ready to be used when required, and accumulates the efforts of a small power acting through a considerable period, ready to be expended as a great power acting through a short time. Farther, this power is completely under control; for by the mere turning of a stop-cock, or the opening or closing of a valve, it can be put in action or arrested at pleasure; and the speed with which a weight is moved, and the height to which it is raised, can be regulated with the greatest nicety.

Apparatus has sometimes been applied in which water flowing from a high level, or compressed air, may be made to act as steam in a steam-engine, for giving motion to machinery. The construction of such apparatus is very similar to that of the steam-engine.



TWENTY-TON HYDRAULIC WHARF OR PILLAR CRANE.



HYDRAULIC FIXED WHARF OR PILLAR CRANE.

In one of the folio plates of this work an illustration of the hydraulic crane is given. We are indebted to Messrs. Appleby for the engraving and for the following description and remarks on the use of hydraulic cranes generally:—

"The use of hydraulic power for working cranes, hoists, engines as motors for capstans, opening and closing dock gates, swinging bridges, &c., is so general, and so well understood by engineers, that it will be unnecessary to describe the system in detail; the following brief description may, however, enable the non-practical reader to form an opinion whether it is adapted for any special object he may have in view, whether for docks, railway depots, warehouses, or establishments of a similar character.

"Assuming that it has been decided to adopt the hydraulic system, it is desirable, but not essential, that the buildings to contain the engines, boilers, and accumulators, should be as central as possible, and these should all be proportioned to the present *and prospective* magnitude of the works, or space should at all events be allowed for the probable duplication of plant.

"The boilers are usually of the Cornish type, and each of the engines is fitted with a double-acting hydraulic pump coupled directly to the end of the piston-rod, and each pump forces the water into an accumulator.

"The accumulator is a vertical cylinder, which is proportioned in diameter and height to the number and power of the cranes or other machines to be employed. This cylinder is fitted with a leather collar or gland, through which works a ram or plunger with a massive crosshead on the upper end, to which is attached an annular weight case surrounding and sliding over the above-named cylinder. The weight case is filled with ballast until the total weight on the ram is equal to (usually) 700 lbs. per square inch; water is then forced in the cylinder or accumulator by the hydraulic pumps, until the ram, loaded as above described, reaches the top of the accumulator. At this moment a self-acting arrangement arrests the motion of the engines, but immediately the ram begins to descend, in consequence of some of the stored power having been used, the engines and pumps are set in motion automatically, and the ram is again lifted.

"It will be clear that the water contained in the cylinder (so long as the weight case is sustained by the ram) will be under the pressure due to the area of the ram and the load on it, and that all the mains taken from this cylinder or accumulator will likewise be under the same pressure (assumed at 700 lbs. per square inch); the mains and branches may be taken to almost any distance, with no loss excepting that due to friction, and as the quantity to be passed is small, if the mains are a reasonable size, this amounts to very little; if, however, the mains are carried to a great distance, an accumulator should be placed at both ends of the works (the mains are frequently carried three to four miles), and small branches are taken from the main pipes to supply cranes, hoists, hydraulic engines, &c., at any point where power is required.

"It will be well to bear in mind that, as the cylinder must be filled every time it is used, exactly the same power is expended in lifting the empty chain as is required to raise the maximum load the same height, and that true economy will be obtained by adopting a treble ram, or some similar expedient, for all loads above ten cwt.; the first cost is of course somewhat greater than if a single ram is used, but it will be amply repaid in the lower working expenses due to the lower consumption of power.

We have already referred to one of the folio plates in this work as illustrating a large crane for use in docks, &c. It is called the Hydraulic Fixed Wharf or Pillar Crane, and the following is a description of it:—

"The twenty-ton crane embodies many improvements, and gives a general idea of the construction adopted for all sizes and for all sweeps. The chief improvement is that the crane is entirely self-contained, the whole of the machinery being carried within the crane structure, obviating the necessity of costly foundation pits close to the crane, and saving the immense ground space occupied by cranes of the old construction, in which the cost of foundations is often equal to the cost of the crane and that of the whole of the machinery; the valve gear being on the crane also simplifies the construction.

"The crane is fitted with three lifting cylinders, giving three lifting powers, for seven, fourteen, and twenty tons; for the lowest power only the centre cylinder is used; for the second power, the two outer cylinders without the centre one; and for the full power all three cylinders are used. Another advantage in this design of crane is that, the cylinders being vertical, the use of a cylinder to overhaul the lifting cylinder is avoided, and a much lighter ball can be used on the lifting chain; the slewing cylinder is double-acting, and will slew the jib a complete revolution.

"The crane jib is constructed chiefly of wrought iron, and can either be raised on a wrought-iron pedestal, as shown, when a great length under the jib-head is desired, or sunk in a pit of masonry."

Lifts or Hoists, worked directly by hydraulic power are now largely employed in warehouses, hotels, and other buildings of considerable height. One of these is the subject of a folio plate supplied to this work by Messrs. Appleby, and of which the following is their description:—

"*The Hydraulic Direct-action Hoist.*—This system is preferred to all others for passenger lifts, on account of the smooth and noiseless action and the almost absolute impossibility that any derangement should occur sufficient to cause an accident. It consists of a hydraulic cylinder equal in length to the height of the desired lift (sometimes seventy feet and upwards), placed vertically in a well or bore hole, and a ram of area proportionate to the work to be done and the pressure of water available. The cylinder is fitted with a gland or leather collar, and on the

head of the ram rests the cage or ascending room, which is guided by suitable guide timbers. The motion is regulated by an equilibrium valve, admitting the water into the cylinder or letting it run to waste. The valve can be controlled from a rod which passes down one corner of the lift, and only requires a gentle pull to stop at any desired floor or to start again.

"These lifts are always fitted with compensating counterbalances, exactly equal to the weight of the cage and the ram at all points of its stroke, ensuring the utmost economy of water in working. The water pressure is obtained in various ways, from an accumulator of the kind described in connection with the hydraulic crane just referred to, and into which the water is forced by steam power and pressure pumps, one accumulator being used for working a number of such lifts together with cranes, capstan engines, dock-gate engines, &c., or it may be taken directly from the water company's mains, if there is a high-pressure service and the water may be used for such a purpose: but in London and in many large towns the companies appear studiously to restrict the use of water for lifts, small water engines, &c.; whilst in Leeds, Bradford, and other towns in that district, where this privilege can be obtained, many water engines, lifts, &c., are used with manifest advantage to the consumer and to the water company.

"To obviate the inconvenience experienced from a defective water supply, recourse is had to a tank placed at the highest elevation available, supplied by a small pump and steam engine; and after the water has been used, it flows to a low-level tank and is again lifted up into the high-level tank, the same water being used over and over again. The supply in the first instance is obtained from a well or the company's main, or from some source near the surface.

"The lift, illustrated in the folio plate, is erected on the premises of Messrs. Gooch and Cousens, of London Wall, London. The ascending-room is six feet by six feet and seven feet high; the room has seats on three sides, and will take twelve persons at one time, and is fitted up like a first-class railway-carriage; the roof is of glass with a lamp in the centre. The sales are held on the top floors of these spacious warehouses, which are about forty feet above the ground floor, the light being so much better there than on the lower floors, and the lift is used to carry the wool-buyers to and from the sale-rooms, or to any floor of the warehouse. The whole of these warehouses have been fitted with cranes and machinery by Messrs. Appleby.

"The cost of the machinery, including large top and bottom tanks, mains, steam pump and boiler for same, was £860; and the cost, including the necessary timber work, sinking cylinder, and erecting the whole, was £250.

"This kind of lift is used in many of the best hotels as well as in public buildings, hospitals, and offices, and even in the large private offices and blocks of buildings which are now erected in commercial towns. A man in charge of the lift makes the full ascent and descent about once every two or three minutes, including stopping to let out or take in passengers at any of the intermediate floors.

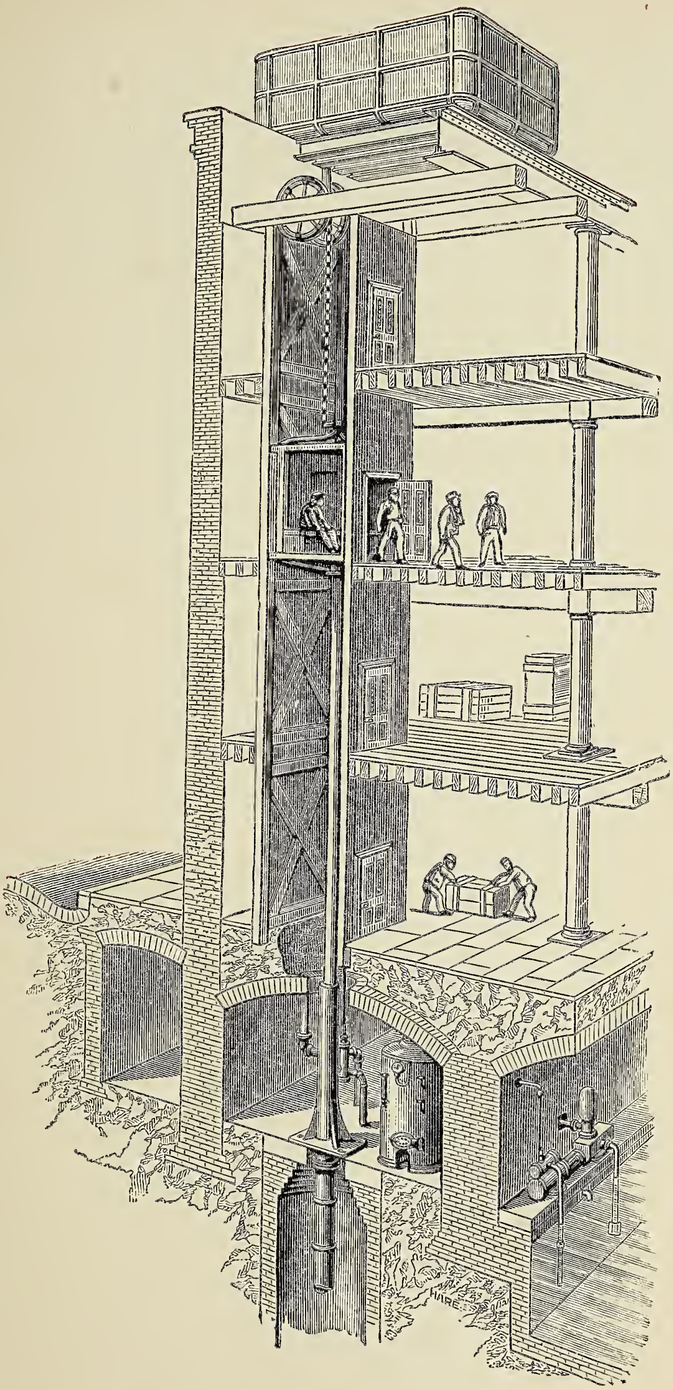
"Lifts of this kind have been erected for use in several royal palaces, the ascending-rooms being 10 to 12 feet square, and luxuriously fitted and decorated.

"A similar form of lift is also much used for banks, to take up the books and bullion from the strong rooms in the basement to the first and second floors, and many are now working with all kinds of pressures, each giving excellent results; of course the greater the pressure available, the *lower* will be the cost of the lift for a given load and height; but the conditions are very variable. A bank-lift equal to 12 to 15 cwt., with a 12-foot lift, working with 60-feet head, taken from a tank fixed on the top of the building, and supplied by the water-company's mains, costs about £130, including erection in London.

"Where no head of water is obtainable either directly from mains or from a tank, the ram is lifted by water being pumped into the cylinder by a pair of pumps fixed on a cistern, and having about the same capacity as the cylinder; the pumps are worked by hand, and being double, a steady, *smooth*, safe, and noiseless motion is obtained, these conditions being most essential in a bank or office. A variety of powers can be given by altering the stroke of the pumps, or working one or both at once, and the lowering is perfectly controlled by a small relief-valve, which allows the water to flow back into the pump cistern; the top of the lift often forms the iron door to the opening, and if the water is confined by the valve in the cylinder, it *securely* locks the opening to the strong room, without any other locking apparatus. This construction is adapted for lifts with a small diameter of ram and cylinder."

The hydraulic jack has a great variety of uses. It is valuable for raising great weights, as in shipbuilding, boiler-making, in warehouses, &c. In America it has been used for lifting whole towns, as in the case of Chicago some years ago. The following is an instance of a similar kind of use in our own country.

"Another difficult and highly interesting engineering feat has just been performed by means of Messrs. Tangye Brothers' hydraulic jacks. It would appear that the foundations of the lower pillars of the basement of a 60,000 spindle mill at Bolton, were discovered some short time since to have subsided, and the pillar bottoms to have seriously shifted, so much so that the whole of the five floors were ascertained to have settled down to a depth in all of at least five inches, owing partly, it is believed, to the presence of a previously unsuspected coal seam. It was ultimately found that it would be necessary to raise six of the pillars, and to bottom and concrete the seam of coal, the operation being rendered the more difficult inasmuch as the weight to be lifted could scarcely be arrived at with any degree of accuracy, the floors of the mill being constructed of wrought iron and concrete, and having arched downwards in subsiding. The work was taken in hand by one



HYDRAULIC DIRECT-ACTION HOIST.

of the proprietors of the mill, who estimated that the resistance could not be less than 100 tons upon each pillar, although by others it was judged in reality to be considerably more. Six fifty ton hydraulic jacks were applied, two to each pillar, and three pillars were lifted at the same time. It would be difficult to explain the operation without drawings, but the jacks worked superbly, as was acknowledged by all who witnessed the operation. We cannot give the exact period of time which was occupied, inasmuch as the work had to be carried on very slowly for fear of cracking the floors when raised. The really striking feature, however, of the operation is the fact that the jacks held this enormous weight for about a week in each case, whilst the foundations were excavated and the concrete put in. It was a dangerous job, but was most successfully carried on, the jacks sustaining their ponderous loads for the unusally protracted period mentioned above without giving way in the slightest degree. Somewhat recently, also, a large chimney stack at one of the South Staffordshire iron works having got dangerously out of perpendicular (owing, it was supposed, to subsidence in the foundations from adjacent mining operations), it was proposed to have it taken down and rebuilt. A trial, however, of Tangye's hydraulic jacks was suggested and adopted, the result being that the chimney stack was most successfully restored to the vertical, having been firmly sustained by the jacks whilst the foundations were excavated and renewed."

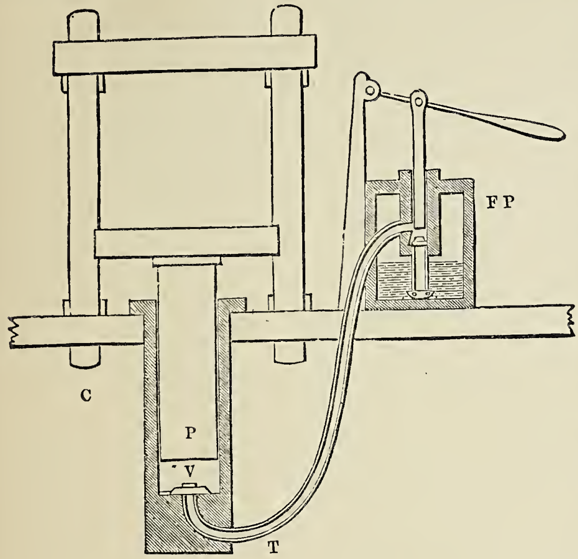


Fig. 241.—The Hydraulic Press.

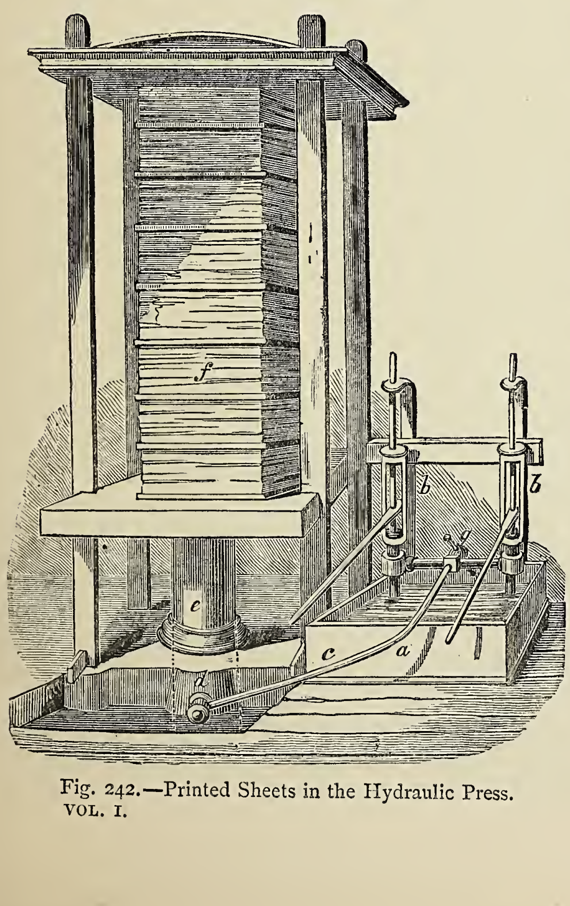


Fig. 242.—Printed Sheets in the Hydraulic Press.

The Hydraulic Press is simply a modified form of the various hydraulic machines that have just been described, but adapted for a great variety of purposes, in which a high and permanent pressure is required. It is frequently called the "Bramah Press," from the name of the inventor. Fig. 241 shows a section of one of these machines.

Near the lower part of the machine is a vertical iron cylinder, C, in which a piston, P, works. At the bottom of the cylinder is inserted a tube, T, whose aperture under the piston is covered by a valve, V. The other end of the tube communicates with a small forcing-pump, F P, by which water is driven through the valve into the lower part of the cylinder, where its hydrostatic action is exerted to raise up the piston. If water were elastic or yielding in the same manner as air, even to a much smaller degree, it would be condensed in the space between the valve and the piston, and the latter would not be raised with any considerable force; but water is so very nearly incompressible, that it will resist almost any force rather than suffer contraction into a smaller bulk. The amount of the force thus resisted depends mainly

on the relative diameters of the piston in the forcing-pump and the piston in the cylinder—the latter being always very much greater than the former. This law or rule has already been explained at p. 288 *ante*.

As already stated, the hydraulic press has a great variety of uses, some of which will be more particularly described under the head of various manufactures. The following illustrates a kind employed in connection with preparing printed sheets for books.

This hydraulic press (Fig. 242), contains apparatus for driving up the bed or stand on which the sheets are placed. There are two pumps, *b b*, worked by handles in the usual manner, and dipping at their lower extremities in the cistern of water, *a*; the water is pumped through the pipe *c* to a reservoir at *d*, where it exerts an upward pressure, which forces the piston *e* against the bed on which the sheets *f* are placed. When it is desired to remove this pressure in order to take away the sheets, a cock is turned at *g*, by which the water is allowed to flow back from the reservoir to the cistern. For the better kind of books, where it is desired to give a smoothness and glossiness to the paper, glazed millboards are inserted among the sheets before the latter are subjected to the press.

The Boomer Press.—This machine has been recently brought out as a mechanical substitute for the hydraulic press already described, and for that reason it is here noticed, although of course entirely out of place in connection with water as a motive or other form of mechanical force. It can be worked either by human or steam power, according to the purposes it is required for. It has been largely adopted for pressing cotton, cloth, wool, paper, hay, and for cider, wine, seed-oils production and other processes. We are indebted to Messrs. John Ladd and Co., of London, for the descriptive matter and the illustrations which follow. (See Figs. 243 to 248.)

"The 'Boomer' Press, for all purposes where pressure is required, possesses several advantages over the Hydraulic.

"*First.*—It is simple in its construction and not liable to get out of order.

"*Second.*—The power accumulates or increases with every turn of the screw, the movement of the follower being very rapid at the commencement of the pressing, gradually diminishing in speed as the power increases and the material under pressure becomes the most dense. The movement of the follower can be regulated to a nicety, being perfectly even and continuous in its action, not intermittent as is the case of the hydraulic.

"*Third.*—The power never yields to the pressure, but is maintained, no matter in what position the arms or levers may rest.

"*Fourth.*—It requires no made foundation, consequently can be placed in any part of a building or moved about on wheels.

"The principle by which the enormous power is acquired is by a combination of four levers or arms working upon toggle-joints, through which passes a right and a left hand screw, the rotation of the screw causing the two joints either to approach or diverge—according to the direction of such rotation—with a perfect uniform motion.

"The sliding standard runs through the top frame, or head-block, and keeps the pressing-plate, or follower, in its true horizontal position, controlling the power, and preventing any end-wise motion of the screw. The gross load is not thrown upon the sliding faces of the screw, but is transmitted through the toggle-joints to the top frame or head-block, connected with the base by the usual wrought-iron pillars.

"The smaller sizes can be worked by hand, one man being able to exert more power than five men with the ordinary screw.

"To apply the power by hand, it is first run down by a wheel at the end of the screw, until the heaviest pressure is required, and then the final pressure is applied by a lever and rachet-wheel in the centre.

"A pressure-gauge is affixed to each press, so that the actual power exerted may be ascertained as the operation proceeds."

Steam, as a Motive Power.

It is not intended, in the present article, to enter into a long or detailed disquisition on the steam engine. Our object will be chiefly to deal with the subject so that those who, constantly in contact (if we may so say) with the engine, may be informed of the most important particulars connected with its construction and working. There are hundreds, perhaps thousands of persons who have directly or indirectly the control of steam engines and boilers, who are all but destitute of an adequate knowledge of their construction and management, and it is chiefly to these that the following remarks are addressed.

That a steam engine is a combination of various pieces of metal, previously wrought to a definite form, is pretty well known; but the relation which these parts bear one to another cannot be distinctly appreciated without a little previous study of the phenomena of steam as a moving power.

That ice, water, and steam are convertible substances, every one knows, and it is also pretty generally known that heat is the agent by which the conversion from one state to another is effected. But it is not so well known that the difference of bulk between a given weight of water and of steam is the true cause of the power of the steam-engine. A cubic inch of water, weighing about 252 grains, may be converted, at at emperature of 212°, or the boiling point, into an equal weight of steam; increasing in bulk, however, whereby a cubic inch of water becomes nearly a cubic foot of steam. How this extensive increase of bulk is brought about, we are little able to say: all which is positively known in the matter being, that a large amount of heat is taken up or absorbed during the process. A cubic inch of water at 212° may be converted into a cubic foot of steam at 212°; yet although the thermometer indicates the same temperature in both, so large a quantity of heat has been absorbed by the steam as would suffice to raise

about one thousand cubic inches of water one degree in temperature. As this large amount of absorbed heat is not perceptible by the usual test (the thermometer), it is called *latent* or "hidden" heat.

But the expansion of an inch of water into a foot of steam would be of little use to the engineer, unless there were means of effecting the subsequent reduction of the steam, and thereby producing a reaction. This reduction is effected by cold, which robs the steam of so much latent heat as to render it incapable of maintaining the vaporific form, and it thence reassumes the form of water.

"These properties of steam, and many others of equal importance, were developed in successive ages, and by different philosophers; and the manner in which they may be made available as mechanical agents will, perhaps, be understood from the following notice of Newcomen's steam-engine, one of the early forms of engine:—A metallic boiler, half full of water, is placed over a furnace or fire, the heat of which converts the water in the boiler into steam; the boiler is closed in on all sides, but it has a little aperture, covered with a valve or plug, which is opened by the force of the steam when its expansive power exceeds the pressure of the valve (see Fig. 249.) A pipe conveys the steam from the boiler to an upright cylinder or barrel, in which a solid piston or plug works up and down. The top of the piston is exposed to the open air, while the bottom is wholly excluded from atmospheric action. Now the air presses on all bodies at the earth's surface with a force of about fifteen pounds per square inch, and the piston is pressed downwards in the cylinder by this force. In order, therefore, to drive the piston upwards, steam is admitted beneath it; and this steam must be raised to a high temperature—greater than 212°—in order that its expanding or elastic force may be more than a balance for that of the atmosphere. The steam, then, drives up the piston; but a question arises, how is it again to descend, so long as the steam remains beneath it? To effect this, a jet of cold water is thrown into the cylinder beneath the piston, and robs the steam of so much heat as to render it incapable of maintaining the vaporific form: it condenses into drops of water, which, occupying only one seventeen-hundredth part of their former bulk, leave an extensive vacuum in the cylinder. The external air has now power to act unresisted, and it depresses the piston. A new admission of steam into the cylinder again forces up the piston, and a new injection of water condenses the steam, produces a partial vacuum, and causes the descent of the piston.

Now, it is easy to see what constitutes the principle of such an engine as this, and what are merely subsidiary details. The external air tends to press down the piston in the cylinder, and we have to employ an antagonist force which shall be alternately greater and smaller than this pressure. This antagonist force is steam at a temperature greater than 212°, and the same steam converted into water, thereby leaving a vacuum in the piston. The arrangement of the fire-grate and flues, so as to impart the greatest amount of heat; the shape of the boiler, and the introduction into it of a safety-valve and gauge-pipes, to indicate the quantity of water and the temperature of the steam; the arrangement of the pipe and valves which admit steam from the boiler to the cylinder; the mode of condensing the steam; and the mode in which the vertical motion is, by the aid of rods, beams, levels, and wheels, made available as a mechanical agent—all these are matters of detail which will be subsequently explained in connection with the existing varieties of the steam-engine.

James Watt, besides practically demonstrating many of the properties of steam indicated above, introduced a vast number of improvements into every part of the machine; and we may now briefly show how the great principle of the steam-engine has been brought into play by these improvements. In his original plans the furnace and boiler were so admirably arranged, that when the fire was too strong, a damper was, by the action of the engine itself, drawn across the flues, to lower the draught; and when the water in the boiler was too low, a valve opened, and more water flowed in. Steam being produced, it was carried along a pipe to the cylinder, and, in so doing, it passed through a valve so contrived as to regulate the quantity of steam admitted according to the amount of power required. The cylinder was not open at the top, as in Newcomen's engine, but was enclosed on all sides; having an internal piston wholly shielded from the external air. The downward pressure of the air was, therefore, here lost; but in lieu of it steam was admitted above the piston as well as below, though not at the same time. Newcomen's cylinder was partially cooled before each downward stroke of the piston by a jet of cold water; but Watt's cylinder must be kept constantly warm, and the condensation of the steam is effected, therefore, in a separate cylinder, kept in a cistern of cold water. Let us suppose that steam admitted above the piston presses it down; a valve is then opened, by which steam is conducted to the condenser, and instantly cooled, whereby a vacuum is formed above the piston. Meanwhile steam is being admitted below the piston, and as the latter has now a vacuum above it, it is forced upwards by the pressure from beneath. The communication between the condenser and the upper part of the cylinder is then cut off, and another opened with the lower part, whereby another series of changes occur, the steam driving the piston upwards and downwards alternately.

It has doubtless often been a matter of some perplexity, both to those who have seen a steam-engine at work, and those who have not, how such a machine can do so many kinds of work—drain a mine, spin a skein of thread, stamp a coin, print a book, or make a pin's head! The explanation lies within a small compass. To the piston of every steam-engine, is attached a metallic rod, which shares the reciprocatory motion given to the piston. The "stroke," or distance traversed by the piston, frequently amounts to several feet; and any machinery

attached to the remote end of the piston-rod is thus moved to and fro through an equal space with great rapidity. This motion being produced, there are abundant means of giving a *circular* direction to it. Let any one witness the mode in which an itinerant knife-grinder produces a circular motion of the wheel by the vertical motion of the treadle and strap, and he will have a very distinct idea of one among the many modes of effecting such a transformation of movement. The circular motion is, in most applications of the stationary steam-engine, first given to a large, heavy, "fly-wheel;" and this fly-wheel may be considered as occupying the point of connexion between the *production* and the *consumption* of steam power. All the complex arrangements relating to the production and management of the steam have performed their wonted part when the fly-wheel is set in motion; and it is after this only a work of wheels, bands, shafts, and other mechanical contrivances, to apply practically the power thus obtained.

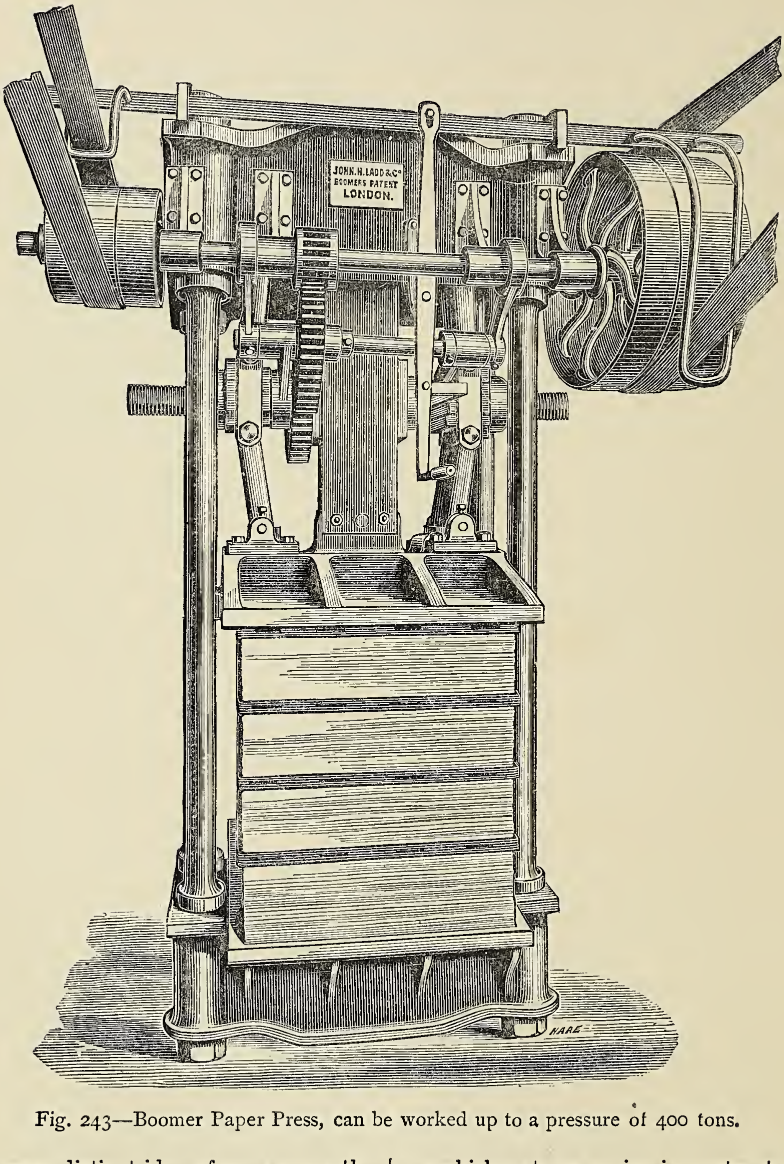


Fig. 243—Boomer Paper Press, can be worked up to a pressure of 400 tons.

Such is a brief outline of the general principles on which a steam engine is constructed. It will now be necessary to enter into a closer investigation into the laws that govern the action of steam, and into a more minute investigation of the various mechanical details that constitute the numerous forms of the modern steam engine, steam boilers, &c., &c.

In the first place we may note that the steam-

engine of the present day may be arranged under three typical forms, viz. :—

1st.—The *high-pressure*, in which the steam after having done its action on the piston, in the cylinder, is then allowed to escape, as in the locomotive, into the open air.

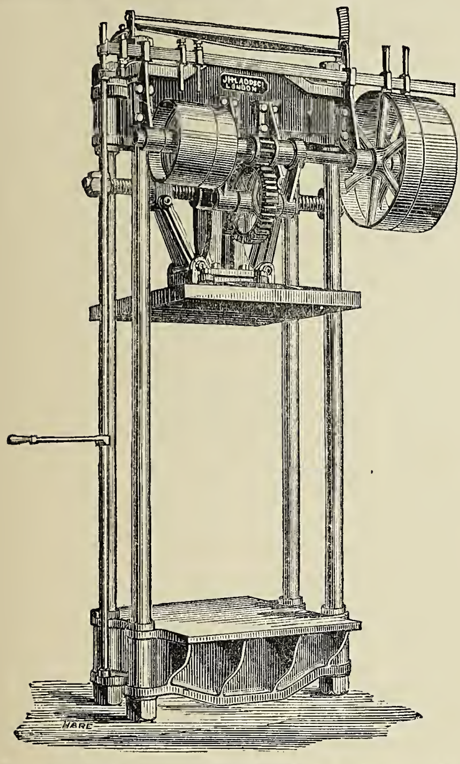


Fig. 244.—Paper Press, can be worked up to a pressure of 200 tons, either by hand or steam power.

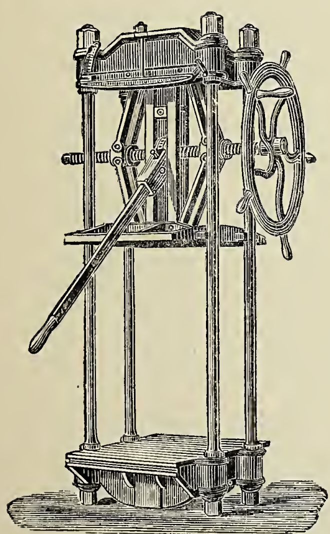


Fig. 245.—Small Paper Press, can be worked by a boy to a pressure of 60 tons.

2nd.—The *condensing engine*, in which the steam after leaving the cylinder is condensed in a separate vessel, as is commonly adopted in many stationary engines, and almost invariably in steam vessels.

3rd.—The *compound* engine, in which high

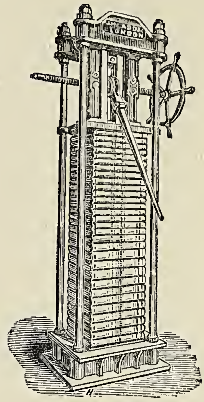


Fig. 246.—Bookbinders' Press.

pressure steam is used in the first cylinder, and then passed through one or more, being at last condensed. This form is specially of modern character, and is being largely adopted on account of its economy of working and for many other reasons that will be subsequently explained.

We now turn to inquire into the nature of steam and the laws which govern its application in the form of the steam-engine, &c. :—

When a liquid is exposed to heat, it expands in bulk; and when the heat is carried to a certain point, part of the liquid rises from the

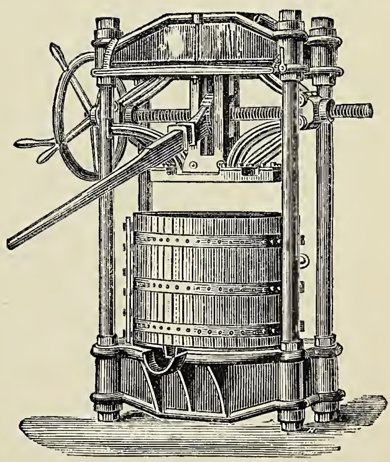


Fig. 247.—Press for Oil, Tallow, Greaves, &c.

rest in the form of vapour, occupying a much greater volume than it did in its liquid condition. It is probable that all substances, solid as well as liquid, are capable of being thus changed into

the vaporous form. Some bodies, such as ether and alcohol among liquids, and iodine among solids, rise in vapour at comparatively low temperatures. Others, again, such as many of the metals, even after they have become liquid under the influence of heat, require very considerable accessions of temperature before they pass into vapour. Water, one of the substances most widely diffused in nature, and therefore most cheaply obtained, holds a middle course in this respect between these extremes, and attains, by no great accession of temperature, properties which render it especially serviceable for human use. It is, indeed, among the most obvious of the beneficient arrangements of Prov dence, that this fluid—almost everywhere accessible, possessed of no corroding power like acids or alkalies, of no intoxicating qualities like spirits, nor of inconvenient gravity like metals—should be at the same time capable of absorbing vast quantities of heat, and of giving it out in the shape of active motive power. It has been proposed to employ the vapours of ether, alcohol, sulphide of carbon, and mercury, for moving engines ; but no advantages from their use in this way have presented themselves, such as could bring them into competition with water. We will, therefore, confine ourselves to it, as the only substance turned practically to account.

At every different temperature at which vapour may exist, its elastic force is different, being greater the greater the temperature, but not proportionally so. When we inquire what is meant by the elastic force of a vapour, we can only say that it is a property common to all aëriform bodies, by which they react on any surface compressing them, or tend to expand into a larger volume than that in which they are confined. There seems, indeed, to exist, a repulsive force among the particles which constitute a gaseous body, pushing them asunder with equal power in every direction, and requiring some contrary compressing force to retain them in their places. We have no example of a gaseous body existing without being contained in an envelope of some kind, or being pressed upon by some surrounding medium. The air at the surface of the earth is pressed upon by the weight of the air above it, and exerts an elastic force exactly balancing the pressure of the superincumbent fluid. If its elastic force were greater than the force compressing it, it would expand and lift the air above it ; or if less, it would collapse under a pressure greater than it could resist. As we ascend higher, the weight pressing on the air is diminished, because there being a certain amount of the atmosphere left below, there remains a less amount above. We find accordingly, that at any height above the earth's surface, the elastic force of the air is diminished in proportion as the pressure upon it is lessened. At the top of a high mountain, like Mont Blanc, the elastic force of the air is not more than half that of the air at the surface. If we were to introduce a drop of oil into a small glass tube closed at one end (Fig. 250), so that the oil should form a film, or diaphragm, across the tube at some point A, we should enclose between A and B a portion of air in the same condition as that surrounding us. If, now, we ascended a mountain, we should find the air-film at points C, D, E, successively, as we attained greater height. Before our ascent commenced, the elastic force of the air in A B pressed the oil-film outwards with exactly the same force as that of the weight of superincumbent air pressing it inwards, and accordingly the film remained at rest. As we ascended, we subjected the film to less external pressure, because we had less weight of air above us ; and accordingly the elasticity of the air in A B overbalanced the pressure, and pushed the film to some such point as E ; not by fits and starts, but gradually as we ascended.

We have now to inquire why there should be any point such as C, where the film could rest ; in other words, why the elastic force of air in the tube, having once overbalanced the pressure of the external air, should again become equal to it, and no longer force the film outwards. The reply to this question involves the consideration of a most important law to which all elastic fluids are equally subjected. It is called Marriotte's law, after the name of the person who gave it to the world, and is to this effect :— *The elasticity of a gas is proportional to its density*—that is to say, the greater the number of particles of a gas we force into a certain space, or the smaller we make the space containing a certain weight of gas, the greater we make its elastic force, and conversely. Referring now to the air in the tube, we find that when the film has arrived at C, the space containing the air is extended from A B to C B, and the elastic force is diminished in like proportion. In fact, the density and elasticity of the air within the film is exactly the same as that of the air without, and the film remains motionless at C as long as this equality subsists. Again, as we ascend, the external pressure diminishes ; the elasticity of the air within pushes the film outwards, and thus extends its space until its elasticity is reduced to an equality with the pressure of the external air ; and so on without limit. In descending, we should find the film moving inwards, according as it became subjected to a greater external pressure, to positions such that the air confined within it became of a density sufficient to balance the pressure. Notwithstanding the extreme simplicity of Marriotte's law, it is one of the greatest importance, and should be thoroughly understood by any one desirous of an acquaintance with the steam-engine, for it applies to steam as closely as to any gas. From this law, it follows, that if we forced air or steam occupying a volume of 2 cubic feet into a vessel of the capacity of 1 cubic foot, we should find the elasticity doubled, because the density would be doubled, or the volume reduced to half. Conversely, if we permitted 1 cubic foot of air or steam to occupy a volume of 2 cubic feet, we should reduce its elastic force to half of what it was before expansion, because we should have doubled its volume, or reduced its density to half of what it was. In order to illustrate these

facts, let us suppose that a cylindrical vessel is fitted with a piston that can slide in it (Fig. 251), having an area of 1 square inch, and that a load of 20 lbs. placed on the piston forced it down to a position C D, an inch from A B, compressing below it the air or steam occupying the part A B D C of the cylinder. We should then say that the elasticity or pressure of the air or steam is 20 lbs. per square inch, because it balances or supports a load of 20 lbs. placed on a piston having an area of a square inch, exposed to its elastic force. If we suppose another inch added to the length of the cylinder, the added space A E F B being totally empty, and the former bottom A B suddenly withdrawn, so that the air or steam had its space or volume doubled, we should find 20 lbs. on the piston, twice as much as it should be to retain the piston in its place, and we should have to replace it by a load of 10 lbs., because the elasticity of the air, or steam, would have become half of what it was before the doubling of its volume. We have already stated that the pressure or elasticity of the air, near the surface of the earth, is about 15 lbs. on every square inch. If then a cylinder like that which we have just described were filled with air under the piston, and placed in a vacuum, there would be required on the piston a load of 15 lbs. to retain it in its place. Were the load less than 15 lbs., the air under the piston would expand in volume and raise it; or were the load greater, the piston would be pressed downwards, increasing the density of the air below it, and proportionally its elasticity, until the load became exactly balanced. But a cylinder of the kind described, filled with air, and not placed in a vacuum, requires no actual weight on the piston, because the surrounding atmosphere affords a load exactly equivalent to the weight that would be required in a vacuum. If the cylinder were filled with steam instead of air, and with no load on the piston, the steam would be said to be at atmospheric pressure, because its elasticity tending to force the piston upwards, is exactly balanced by the pressure of the atmosphere tending to force it downwards. If the piston required a load of 15 lbs. upon it, the steam would be said to exert a pressure of two atmospheres, or of 15 lbs. above atmospheric pressure. So, if the steam sustained loads of 30 lbs., 45 lbs., 60 lbs., &c., placed on the piston, its pressure would be called that of 3, 4, 5, &c., atmospheres; or of 30 lbs., 45 lbs., 60 lbs., &c., above atmospheric pressure.

The pressure or elasticity of fluids, such as air or steam, is often expressed in terms of inches of mercury, or of the height of column of mercury which they sustain. It happens that 2 cubic inches of mercury weigh very nearly 1 lb., and that 30 cubic inches weigh, consequently, about 15 lbs. Now, if we suppose a tube, having 1 square inch of sectional area, bent as in Fig. 252, and closed at both ends A and D, were filled with mercury to the height of 30 inches in one limb above the level in the other, the part A B being a perfect vacuum, and the part D C filled with air, since the weight of the column 30 inches high is 15 lbs. this pressure of 15 lbs. is communicated through the mercury in the bend to the air in C D, which consequently reacts with an elastic force equivalent to 15 lbs. on the surface of the mercury exposed to it. That is to say, the elasticity or pressure of the air in C D is 15 lbs., or 1 atmosphere; and the tube might be opened at D to the ordinary pressure of the atmosphere without effecting any change in the equilibrium of the mercurial column. The instrument in this form would become the ordinary barometer, which measures the pressure or density of the atmosphere by the height of a mercurial column sustained in a tube, every 2 inches of height of mercury corresponding to 1 lb. of pressure per square inch.

If a bent tube (Fig. 253) were connected with a vessel A containing water, on heat being applied to the water, steam would be generated in A, and press, by its elastic force, the mercury downwards in one limb of the tube and upwards in the other, until it attained such a position that the excess of weight of mercury in the one limb, and the pressure of the atmosphere on its upper surface C, should exactly balance the elastic force of the steam in A. If the height of C above B were 60 inches, the steam would be said to exert a pressure of 60 inches of mercury, or 30 lbs. per square inch above atmospheric pressure, or to have a total elasticity of 3 atmospheres.

We have already said that the elasticity of steam is greater the greater its temperature. There is no simple rule for calculating the pressure due to any given temperature, as the law which governs its variations is of rather an abstruse character. The following table of the pressures and corresponding temperatures of steam, or the vapour of water, is compiled from the results of numerous experiments made with a view to establish some law on the subject.

In a work like this we must abstain from the discussion of this law, on account of the advanced analysis required for its investigation. Nor need we offer a formula for calculating the pressure corresponding to a given temperature, as the table contains results sufficiently accurate for all practical purposes. The table only applies to the case of steam in a boiler, or vessel, in contact with the water from which it is generated. Were we to remove any portion of steam into another vessel, and then subject it to heat without water being in contact with it, we should simply expand its volume, as we should air or any other gas, by an increase of temperature; or confining its volume elevate its pressure according to a totally different law. Or, were we to remove the steam to a separate vessel, and there cool it, a portion would be condensed, as will be afterwards explained, and the remainder would expand to fill the void, at a pressure reduced according to Marriotte's law.

In the first column of the table, the temperatures are marked in degrees of Fahrenheit's thermometer.

The second contains the pressures in atmospheres corresponding to the temperatures.

The third gives the pressures in inches of

mercury, or the heights in inches of mercurial columns capable of balancing the elasticities.

The fourth column gives the pressures in pounds per square inch above that of the atmosphere; or the loads in pounds required, in addition to that of the atmosphere, to keep down a piston having an area of 1 square inch pressed upwards by the steam.

Temperature, Fahrenheit	Pressure in Atmospheres.	Pressure in inches of mercury.	Pressure in lbs. above atmospheric.
60°	0·017	0·5	$14\frac{3}{4}$ below.
120°	0·120	3·6	$13\frac{1}{4}$ „
180°	0·500	15	$7\frac{1}{2}$ „
212°	1·000	30	0 above.
250°	2·000	60	15 „
275°	3·000	90	30 „
290°	4·000	120	45 „
305°	5·000	150	60 „
320°	6·000	180	75 „
344°	8·000	240	105 „
372°	12·000	360	165 „
432°	20·000	600	285 „

We would remark, that for temperatures below 180° and above 344° the results are somewhat uncertain. It is within these limits, however, that any practical application of the table can be required, for we seldom have to do with steam pressing with elastic force of less than sented to its expansion, with the pressure due to its elasticity. The volume of steam produced from a given quantity of water has been variously stated; but we believe it may be very correctly estimated at 1,600 times that of the water when the pressure is equivalent to 1 atmosphere. That is to say, a cubic inch of water contained in a vessel open to the air, when boiled off into steam, occupies 1,600 cubic inches of bulk, and forces the air contained in the vessel away to the extent of that expanded volume; or expands with a force of 15 lbs. on every square inch, which is the measure of the atmospheric pressure, and therefore of the force resisting the expansion of the steam. But had the vessel containing the steam a volume of only 800 cubic inches, or half that to which the steam would expand at atmospheric pressure, then the density of the steam being doubled —or, in other words, the number of particles crowded into the space being doubled—the pressure on every part of the vessel would be doubled also. If the cover of the vessel were a

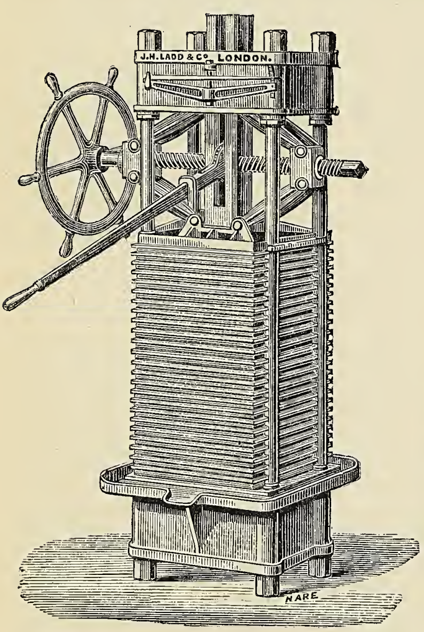


Fig. 248.—Bookbinders' Press.

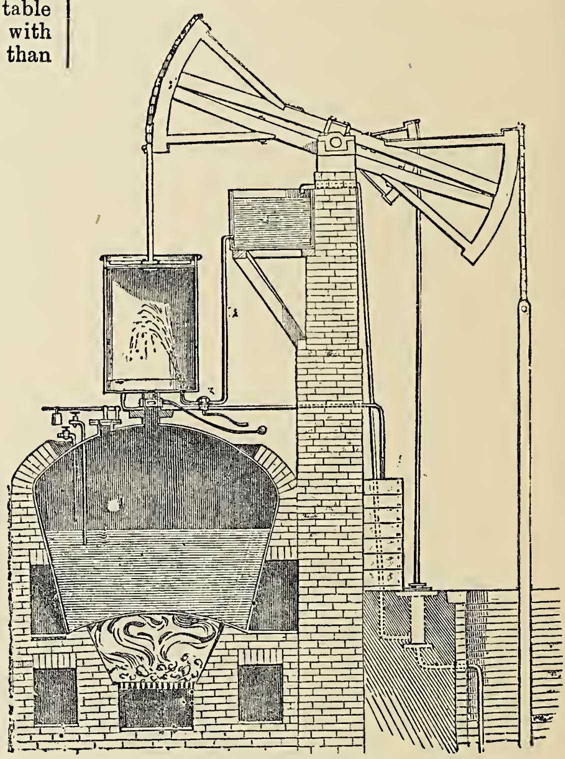


Fig. 249.—Newcomen's Steam-engine.

half an atmosphere on the one hand, or with pressures above eight or ten atmospheres on the other.

The great secret of the power derivable from steam, lies in the fact that a small volume of water is expanded by heat into a large volume of elastic vapour, tending to occupy a greatly increased space, and forcing any obstacle pre- movable piston having one square inch area, it would in this case require a load of 15 lbs., in addition to the atmospheric pressure upon it, to keep down the elastic steam within.

Looking at the question generally, we see that the volume occupied by steam from a certain quantity of water is inversely as the pressure, because the pressure is as the density,

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and the density is inversely as the volume. The following is the rule for calculating the volume of steam at any pressure, produced from a given volume of water.

Rule.—Multiply the volume of water by 1,600, and divide by the pressure in atmospheres.

Example 1.—Required the volume of steam at 4 atmospheres (or having a pressure of 45 lbs. per square inch above atmospheric pressure) generated from 3 cubic feet of water.

$$\frac{3 \times 1600}{4} = 1200 \text{ cubic feet of steam.}$$

Conversely, to find the quantity of water necessary to generate a given volume of steam at a given pressure.

Rule.—Multiply the volume of steam by the pressure in atmospheres, and divide by 1,600.

Example 2.—Required the water necessary to generate 1,200 cubic feet of steam at 4 atmospheres.

$$\frac{1200 \times 4}{1600} = 3 \text{ cubic feet of water.}$$

Example 3.—A cylinder 12 inches diameter and 20 inches long is filled 120 times per minute with steam, having a pressure of 30 lbs. above that of the atmosphere ; required the quantity of water necessary to generate the steam.

The area of a circle 12 inches diameter is 113 square inches, and the capacity of the cylinder is $113 \times 20 = 2260$ cubic inches. This capacity filled 120 times gives a volume of steam $= 2260 \times 120 = 271,200$ cubic inches. As the steam presses with 30 lbs. above that of the atmosphere, or altogether with 45 lbs., that is with 3 atmospheres, the volume of water is $\frac{271200 \times 3}{1600}$ $= 508\frac{1}{2}$ cubic inches.

From these examples it is evident that a great force can be obtained by subjecting water to the action of heat. Just as a few grains of gunpowder on being ignited become suddenly transformed into a large volume of elastic gases, which by their expansive force propel a ball with great velocity, or burst asunder the solid rock ; so a small quantity of water heated above 212° is changed into a perfectly elastic vapour, pressing upon the envelope containing it, and forcing any body, opposing its expansion, through a space sufficiently great to permit its enormous increase of bulk.

But not only to the expansion of its volume does vaporised water owe its excellence as a moving force, for its increased volume can be suddenly reduced to a small bulk by the removal of heat which is necessary to its vaporous condition; and whatever force the steam exerted in expansion, is returned again by its condensation.

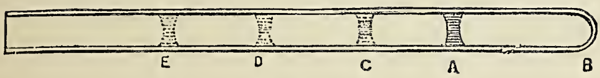


Fig. 250.

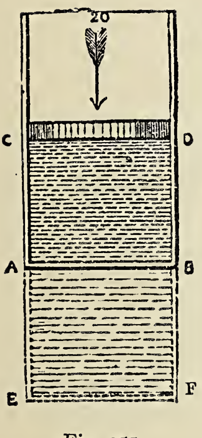


Fig. 251.

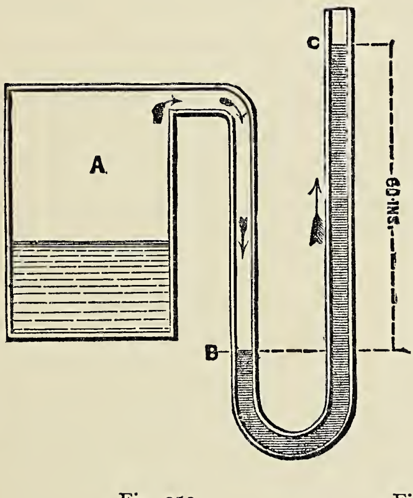


Fig. 253.

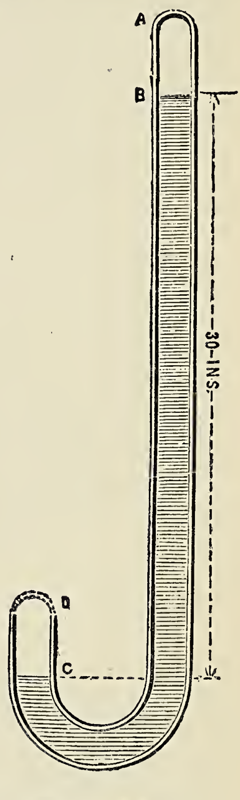


Fig. 252.—The Barometer.

Thus if a vessel containing 1 cubic inch of water, and 799 cubic inches of air, were heated so as to turn the water into steam at twice the atmospheric pressure, the steam would force out the air and occupy its place; acting as it expanded with a pressure of 15 lbs. on every square inch above that of the atmosphere. Were the vessel now cooled so as to reduce the 800 cubic inches of steam to 1 cubic inch of water, the vacuum left by the condensed steam would be immediately filled by air pressed into it by the surrounding atmosphere with a force of 15 lbs. on every square inch. Were the vessel fitted with a piston or partition capable of sliding upwards or downwards in it, without permitting the passage of fluid round its edges, the effect would be the same; for if the piston at A (Fig. 254) were in contact with the water before boiling, and raised to B by its expansion into steam on heat being applied, it must in rising, have been subjected to a pressure of 30 lbs. on every square inch of its under surface, so as to overbalance the atmospheric pressure on its upper surface by 15 lbs. On cold being applied so as to reduce the steam to its original volume of water, the pressure on the under surface of the piston being removed, that of the air on its upper surface again forces it downwards from B to A, its original position. Thus, both in the ascent and in the descent there is developed a force, applicable to the movement of machinery properly connected with the moving piston. In order that we may attain some notion of the amount of this force, let us suppose that the piston has an area of 1 square foot, and can rise and fall 2 feet, and that we have the means of generating and condensing the steam in the vessel 50 times in every minute.

Since 1 square foot = ...	144 sq. in.,
And on every square inch the pressure is	15 lbs.

The total pressure on the piston is 2160 lbs.

This force is moved 2 feet up and 2 feet down 50 times per minute, or through a space of 200 feet per minute, and is equivalent to $2160 \times 200 = 432{,}000$ lbs. moved through 1 foot per minute. A horse-power being reckoned at 33,000 bs. moved 1 foot per minute, the force of the piston, as we have estimated it, is equivalent to $\frac{432000}{33000} = 13$ horse-power. From this example it will appear that by increasing the size of the piston, the distance through which it is moved, the rapidity of its alternations, and consequently the means of generating and condensing the steam, almost unlimited power can be attained.

In many steam-engines advantage is not taken of the power derivable from the condensation of the steam—its mere expansive power is employed; and, after having done its work, the expanded steam is allowed to escape into the atmosphere. This system is adopted for the sake of economy, lightness, and simplicity in the construction of the engine; and such engines are called *high-pressure* or *non-condensing*: *high-pressure*, because the steam must exert a pressure considerably higher than that of the atmosphere against which it has to act; or *non-condensing*, because the steam is not condensed after having done its work. In other steam-engines, called *low-pressure* or *condensing* engines, although greater power is derived from the steam, yet the machinery is rather more complex and heavy, and more liable to derangement; also a large supply of cold water is necessary to effect the condensation of the steam. Of late years many engines have been advantageously employed, in which the steam is first caused to act as it does in a non-condensing engine; but instead of being blown off into the air, it is afterwards made to do duty as in a condensing engine. Such are called *combined* or compound engines, because the principles of expansion and condensation are combined in their action to a greater extent than in most others. Each of these forms of the steam-engine will be fully described as we proceed.

Boilers.—Steam boilers have been frequently mentioned in general terms in our previous pages, and several illustrations of them have been given. In their earlier days cast iron was often employed as a material for their construction, but it need hardly be stated that explosions, which were in many cases fatal, constantly occurred. The materials now used are entirely iron and steel, the latter, having of late years been largely adopted. The old-fashioned flue-boiler has quite gone out of use and has been supplanted by the tubular boiler. The characteristic differences of these two types have been pointed out already at page 217, and on that page and the previous one illustrations are given with a general description of the old and modern boiler. Copper, once used, is now never employed on account of its expense and for other reasons. In devising a good boiler, the problem is to obtain the greatest quantity of steam, or to boil off the greatest weight of water with the least weight of fuel consistently with due simplicity, durability, strength, and economy of material and labour in its construction. It must be a vessel capable of containing water, and affording space for steam generated from it: every part of it being exposed to the pressure of the steam within, it must be capable of resisting this bursting force; and in its construction, precautions must be taken for safety in case of the pressure tending to exceed the strength provided to resist it. A certain portion of its surface must be exposed to the action of the fire; and as the materials which we have to use in its construction, suffer when exposed to excessive heat, and as we cannot, consistently with economy, afford to apply any portion of our fuel ineffectually, we must make provision for having the interior of the fire-surface covered with water to receive the heat communicated through it.

The most simple kind of boiler is one of cylindrical form, with hemispherical ends (commonly called the egg-ended boiler (Fig. 255), placed horizontally, with a fire arranged under it, so that the direct heat of the fire, and of the

heated products of combustion in their passage to the chimney, act through the metallic casing on the water within. The water only partially fills the boiler, leaving a space above it for steam, which is conducted to the engine by a pipe leading from the top of the boiler.

It is found by experiment, and indeed it seems to be a reasonable conclusion, that, within proper limits, having a certain quantity of fuel to dispose of, the larger the surface of water over which the heat developed from combustion is spread, the greater will be the quantity of water turned into steam. In fact, it becomes the object of the engineer to allow as little as possible of the heat to escape by the chimney, and consequently to arrange his boiler in such a manner as to make the water absorb the greatest available quantity of heat, by exposing the largest possible surface to the combustion, and disposing that surface in the best manner.

The strongest form in which a vessel can be made, when it is intended that it shall resist internal pressure, is that of a spherical shell. If, then, in the construction of steam-boilers strength alone were studied, the spherical form would be generally adopted. But of all forms of vessels, the spherical is that which has the smallest surface in proportion to its capacity, and it is consequently ill-adapted for the purpose of a boiler where a large amount of heating surface is important. Next to the spherical in point of strength, and superior to it in respect of superficial area, is the cylindrical form, with hemispherical or rounded ends (Fig. 255) ; and accordingly this form is sometimes adopted for steam-boilers.

Fig. 254.

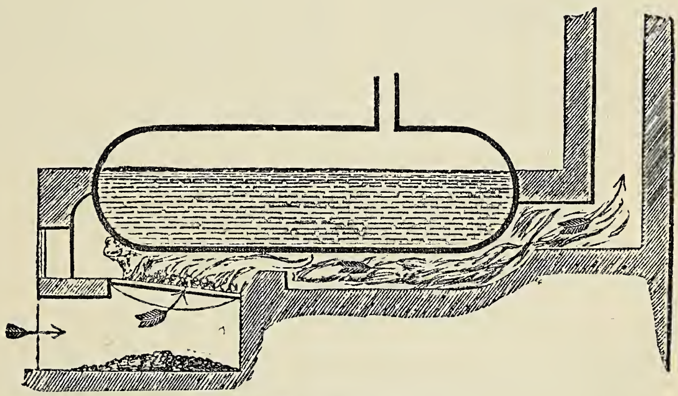


Fig. 255.—The Egg-ended Boiler.

In order to render available as much as possible of the surface for receiving the heat, the heated products of combustion are not permitted to escape directly from the fire into the chimney, but are carried round the boiler by flues generally in the manner shown in Figs. 256—258. The boiler is placed on two banks of brick-work A A, between which are fixed the fire-bars B, so that the flame may play on the bottom of the boiler. The products of combustion, heated to a high temperature, pass along under the bottom of the boiler, upwards at the far end C, thence along the side flues D D formed by brick-work, till they finally proceed by any convenient flue or channel E to the chimney. By this arrangement a large portion of the heat contained in the products of combustion is absorbed during their passage along the bottom and side surfaces of the boiler, and is given to the water contained in it ; while the brick-work, being a very imperfect conductor of heat, permits very little to escape ineffectively. The power of a boiler arranged in this manner depends upon the extent of fire-grate, or quantity of combustible matter consumed in the given time, and the superficial area of boiler on which the products of combustion play in their course towards the chimney. That there should be some relation between those quantities will be evident from the following considerations. If the quantity of fuel consumed be very great while the flue-surface is small, the products of combustion will not have sufficient opportunity for parting with their heat, and will, therefore, carry up the chimney, and waste, a large amount of heating power, which, by better arrangements, might be made to tell upon the water. If, on the other hand, the fire-grate be too small, while the fire-surface is large, the products of combustion will have parted with their heat before reaching the chimney—a large portion of the flue-surface will thus be rendered useless, the draught (caused by the ascent of heated air in the chimney) will be sluggish, and the combustion slow. We believe that, practically, it will be found advantageous to adopt the following rules as to size of fire-grate and quantity of flue-surface in a boiler, such as we have described—the cylindrical, egg-ended boiler.

To the diameter of the boiler, multiplied by its length, add one-half : the result may be taken as the flue-surface ; and this product (in square

feet) should be 10 times the horse-power. Thus in a boiler 4 feet 6 inches diameter, and 15 feet long:—

Since 15 feet $\times 4\frac{1}{2}$ = . . .	$67\frac{1}{2}$ sq. ft.
Add one-half	$33\frac{3}{4}$,,
The flue-surface may be taken at	$101\frac{1}{4}$

Or equivalent to 10 horse-power. Again, for every horse-power there should be $\frac{3}{4}$ths of a square foot of fire-grate. For 10 horse-power there should therefore be $7\frac{1}{2}$ square feet of fire-grate, a surface that might be made up by taking the length of the fire, 3 feet 9 inches, and the width 2 feet, since 3 feet 9 inches $\times$ 2 feet = $7\frac{1}{2}$ square feet.

The converse rule for finding the dimensions of a boiler suitable to a given power is the following:—From 10 times the horse-power subtract its $\frac{1}{3}$rd part, and the result will be the product of the diameter by the length. Thus, to make a boiler of 10 horse-power:—

Since 10×10 = ...	100
Subtract $\frac{1}{3}$rd = ...	$33\frac{1}{3}$
The product of diameter $\times$ length =	$66\frac{2}{3}$

We are at liberty to take any convenient diameter and length that might make up this product within proper limits. Thus making the

	ft.		ft. in.		sq. ft.
Diam.	3,	the length must be	22 3,	product	$66\frac{3}{4}$
,,	4,	,, ,,	16 8,	,,	$66\frac{2}{3}$
,,	5,	,, ,,	13 4,	,,	$66\frac{2}{3}$
,,	6,	,, ,,	11 2,	,,	67
,,	7,	,, ,,	9 6,	,,	$66\frac{1}{2}$

Any of these dimensions may be chosen according to the particular circumstances of the case. Were we to take a diameter smaller than 3 feet, with a greater length than 22 feet, or a diameter greater than 7 feet, with a length less than 9 feet 6 inches, we should find practical difficulties in fixing and working, and lose useful effect from the extreme lengthening or shortening of the flues.

When it is desired to obtain greater heating surface within a smaller space, it is found very advantageous to construct the boiler of cylindrical form, with a cylindrical flue or tube passing through the water; so that not only may the exterior surface exposed to the flues receive heat from the products of combustion, but also the interior surface of the tube. When

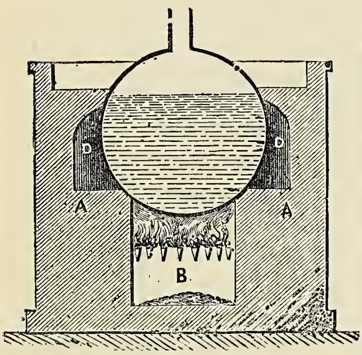


Fig. 256.—Transverse section of an Egg-ended Boiler.

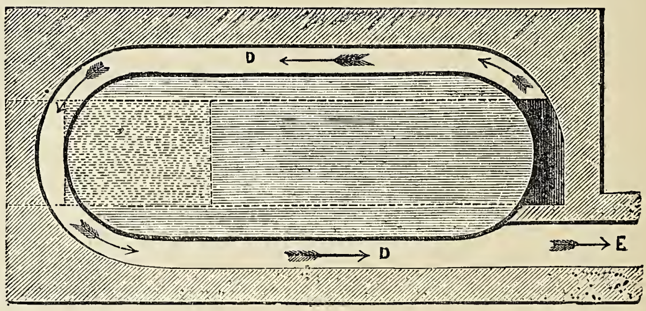


Fig. 258.—Plan of an Egg-ended Boiler.

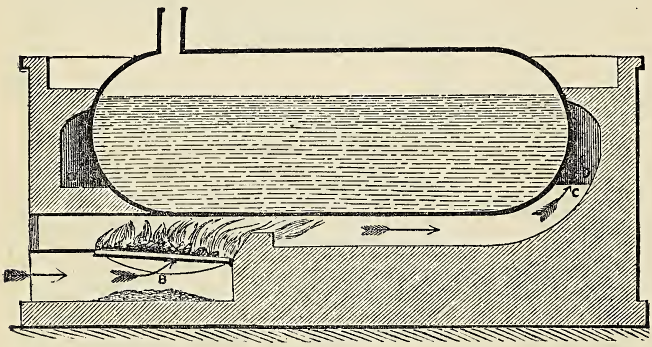


Fig. 257.—Longitudinal Section of an Egg-ended Boiler.

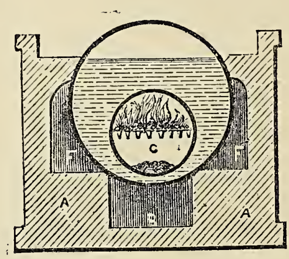
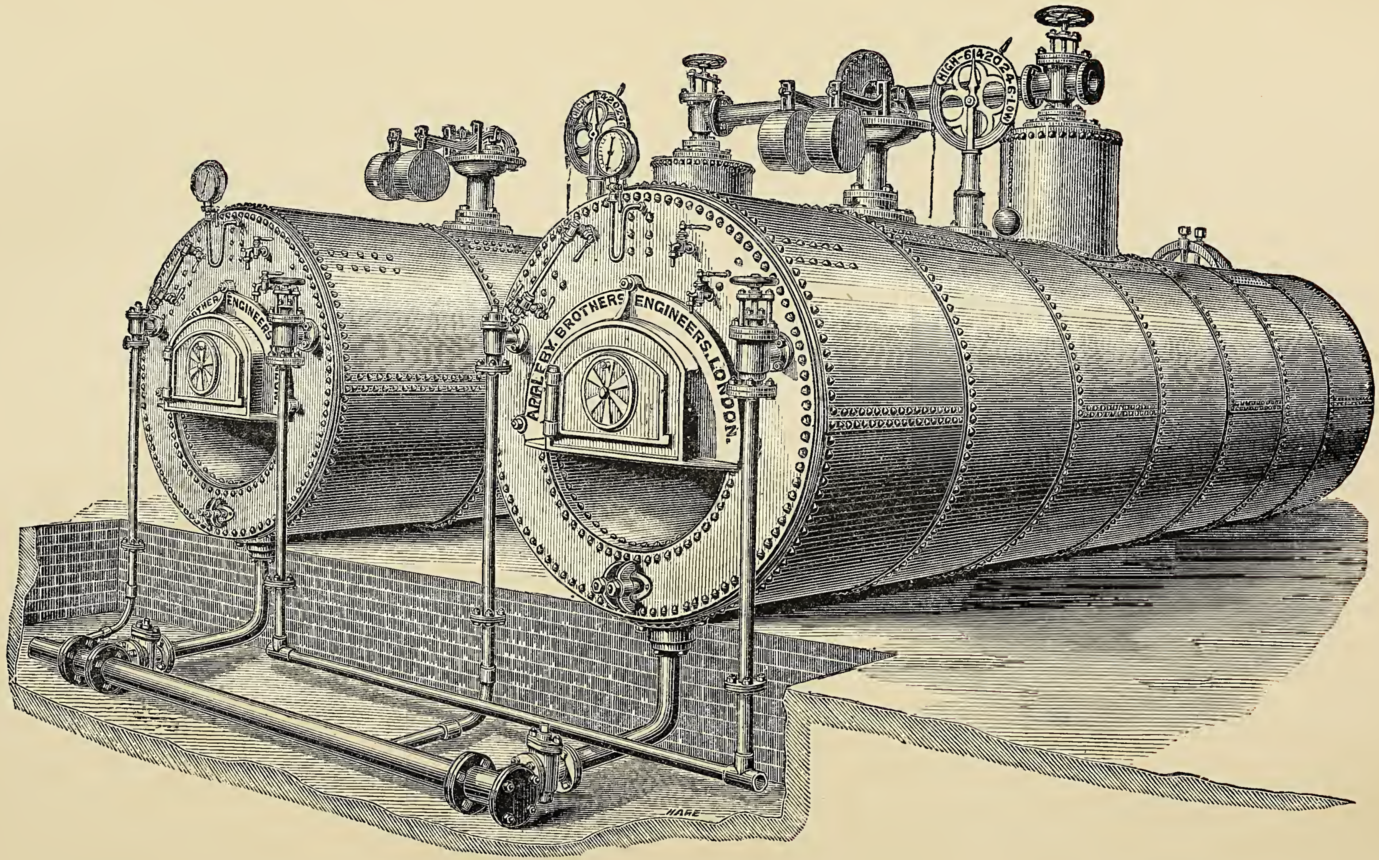


Fig. 259.—Transverse Section of a Cornish Boiler.



A PAIR OF CORNISH BOILERS.

this tube is made of sufficient size to admit the fire within it, as in Figs. 259, 260, and 261, the boiler is called a Cornish boiler, from the circumstance of its being first extensively applied with excellent effect in Cornwall. The arrangement of flues for a Cornish boiler is generally similar to that represented in the figure. The boiler rests on two banks of brick-work A A, with a space for the bottom flue, B, left between them. The fire-grate is fixed at C, in the front portion of the tube; and the products of combustion pass along the tube, spread at the end E into the two sides flues F F, descend at G G to the bottom flue B, and pass thence to the chimney. The quantity of flue-surface in a boiler of this kind exceeds that in the simple cylindrical boiler by nearly the internal surface of the tube. But as the hot products of com-

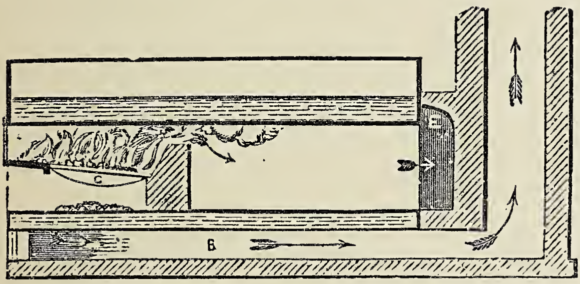


Fig. 260.—Longitudinal Section of a Cornish Boiler.

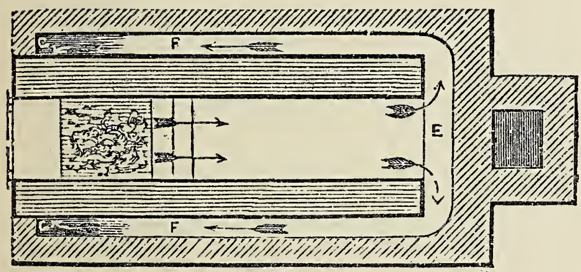


Fig. 261.—Plan of a Cornish Boiler.

bustion pass chiefly along the upper side of the tube, and leave its lower side generally covered with a coat of non-conducting soot and ashes, we cannot safely reckon much more than half the surface of the tube as effective heating surface; that is, $1\frac{1}{2}$ time the tube's diameter multiplied by its length.

In order, then, to estimate the power of a Cornish boiler, we should calculate the external surface as before, and add to it the product of $1\frac{1}{2}$ time the diameter of the tube by the length for the total effective surface; allowing 10 square feet for every horse-power.

Or, more simply:—To the external diameter add the diameter of the tube (in feet) multiply by the length, add one-half to the product, and divide by 10 for the horse-power of the boiler.

Example.—A Cornish boiler, 5 feet diameter, and 12 feet long, has a flue-tube 3 feet diameter: required its power.

Diameter of boiler	5 feet
Add diameter of tube. . . .	3 ,,
	8 ,,
Multiply by length	12 ,,
	96 sq. feet.
Add one-half of 96 = . . .	48
Divide by	10) 144
Horse-power of boiler . . .	$14\frac{1}{2}$ nearly.

The converse operation for finding the dimensions of the boiler when the power is given, would be:—From 10 times the power substract its $\frac{1}{3}$rd part; and the remainder gives the product of the length by the sum of the external and internal diameters.

Example.—Thus, for a boiler $14\frac{1}{2}$ horse-power—

Since $10 \times 14\frac{1}{2} =$.	145
Subtract $\frac{1}{3}$rd of 145	$48\frac{1}{3}$
	97 nearly.

Thus, 97 is the product of the length by the sum of the external and internal diameters.

In this case, again, we must consult the circumstances of position for determining the suitable length and diameters. The diameter of the tube should not greatly exceed half that of the boiler, because there should be an ample covering of water over all the heated surfaces. And again, it should not be less than 1 or 2 feet, because it must admit sufficient area of fire-grate without excessive length. The fire-grate in the case given, reckoning $\frac{3}{4}$ths of a square foot per horse-power, should be about 11 square feet; and as a length of fire exceeding 5 or 6 feet would become inconvenient, we must take it at least 2 feet in breadth—that is to say, the diameter of the tube must be 2 feet. The diameter of the boiler might then be 4 feet, and the length would be for these diameters $\frac{97}{2+4} = 16$ feet. Were we to take the diameters as 3 feet for the tube and 5 feet for the boiler, the length would be $\frac{97}{3+5} = 12$ feet.

We believe it will be found practically advantageous to make the length a little more than three times the diameter of the boiler, the diameter of the tube being rather more than half that of the boiler. For $14\frac{1}{2}$ horse-power, according to this proportion, we should have

Diameter of boiler . . .	4 feet 6 inches
Diameter of tube	2 ,, 6 ,,
Length of boiler	14 ,, 0 ,,

Fig. 262 represents a Cornish boiler in its setting, with a portion of the latter taken away to show the boiler and one of the outside flues. The following are its chief parts :—S is the safety valve and weight; P the pipe conveying the steam to the engine; G the pressure gauge; C the water and steam cocks, facing a glass gauge, through which the height of the water in the boiler may be seen; D the furnace door, and A the ash-pit. The different fittings, such as the safety valve, cocks, &c., will be more particularly described hereafter.

Among the folio plates of this work is a representation of two Cornish boilers, ranged side by side with all the necessary fittings.

In some cases, where the dimensions of the boiler are considerable, two or more tubes are introduced, as in Fig. 263. It is known as the Lancashire Boiler. The tubes are always placed as low as possible, allowing four to six inches between them and the outer casing, in order that their upper and hottest surfaces may be well covered with water, without interfering inconveniently with the steam space above. This form has some special advantages, especially when great power is required. In large boilers the two flue tubes form good stays for the flat ends; the fire grates can be made of the proportions which give the greatest economy (very large grate surfaces having been proved to be less economical than those of moderate dimensions). If the flues are stoked alternately a more even temperature is maintained, the heat in one furnace is always at its highest when the other is at its lowest, and the two flues converging into one combustion chamber, it follows that the gases from the hottest furnace ignite and consume the thick smoke from the other which is being stoked, so that no unconsumed products ought to escape from the chimney in the form of black smoke.

A range of large boilers are often fitted with lifting bridges, a tube connecting the two furnaces in the front, and after a furnace has been newly fired, the bridge is lifted by a lever in the front of the boiler, and the whole of the smoke is made to pass over the other furnace. In all large works there is at least *one* boiler more than is necessary for daily use, so that any of the boilers may be laid off for periodical examination and repair when it is required.

Marine Boilers.—To attempt a description of only a few types of boilers as now used in steam vessels would be impossible, as it is unnecessary, for the locomotive type is now generally adopted with special modifications of form. One of the old-fashioned flue boilers, as then employed, has been illustrated at page 216 *ante*, Fig. 162, while the principle of the modern tubular boiler may be judged of from inspecting Fig. 163, page 217, where remarks are made contrasting the enormous increase of power obtained by using a multitubular boiler. By way, however, of still further impressing on the mind of our readers the defects of the old flue system, we may draw attention to the cut, Fig. 264, given on page 308.

In this F F represent the furnaces. The arrows show the direction of the hot air through the flues *f f f* to the chimney C. It will be seen that an enormous waste of heat must ensue from the great size of the flues.

Locomotive Boilers.—Had it not been for the invention of the tubular form of boiler, the modern locomotive and our present railway speed would have been impossible, because the locomotive requires immense power concentrated in a small space, and great strength of boiler, to bear pressure, now sometimes used to the extent of 200 lbs. per square inch.

A general idea of the construction of a locomotive boiler may be gathered from the following remarks and illustrations, Fig. 265 :—

The body of the boiler A is cylindrical; at one end B is the fire-box, surrounded by water space; at the other end C is the smoke-box, surmounted by the chimney. In the body are arranged numerous small tubes completely surrounded by water, through which the products of combustion pass in their progress from the fire to the chimney, delivering the greater portion of their heat to the surrounding water. The evaporating power of a boiler of this kind is very great, as we may readily believe on calculating the amount of heating-surface in a boiler of the following dimensions :—

Fire-box inside, 3 feet 6 inches $\times$ 3 feet 6 inches $\times$ 3 feet 6 inches, has 60 square feet actually exposed to the fire, and therefore most valuable as heating-surface. 120 tubes $2\frac{1}{2}$ inches diameter and 10 feet long, give 800 square feet of effective flue surface; the whole, including smoke-box, being contained in a space about 13 feet long, 4 feet 6 inches wide, and 4 feet 6 inches high, and yet being equivalent to 80 or 90 horses' power.

Those who desire to study more fully the modern locomotive boiler and engine, are referred to works specially devoted to that subject, and also such periodicals as *Engineering*, *The Engineer*, *Iron*, &c., in which the new forms that are constantly coming out are both described and illustrated. But a sufficient knowledge of most of the details may be gathered from one of our folio plates, illustrating a four-wheeled tank engine, in which a longitudinal section is shown. We are indebted to Messrs. Appleby for the engraving; and its description, both of engine and boiler, has been extracted from *Engineering*.

"This little engine has outside cylinders 8 in. in diameter, with 15 in. stroke, these cylinders being placed at an inclination of 1 in 5, and being situated at a distance apart, transversely, of 4 ft. 2 in. from centre to centre. The engine is carried on two pairs of coupled wheels 2 ft. 3 in. diameter, and placed 5 ft. apart from centre to centre, this short wheel base being adopted to allow the engine to traverse freely the sharp curves met with on the line. The valve gear is arranged externally, the eccentric being placed on an overhung crank. The boiler is 2 ft. 8 in. in diameter inside, and 7 ft. 6 in. long from smoke-box tube-plate to back plate of fire-box casing. The fire-box casing is 3 ft. 6 in. long, and extends 2 feet 11 in. below the centre line of boiler at the front, and 1 ft. $10\frac{1}{2}$ in. at the

rear end. The width of the fire-box casing at the lower part is 2 ft. 2 in., its form being shown by the transverse section. The fire-box is 3 ft. long by 1 ft. 8½ in. wide, and has a mean height of 2 ft. and ½ in. above the fire grate. The boiler contains 72 tubes, 1½ in. diameter by 4 ft. 2 in. long between the tube plates, the external tube surface being thus 117½ square ft. The fire-box surface is about 23½ square ft., thus making the total surface 141 square ft. The grate area is 5·13 square ft. The engine has inside and outside frames, the total width outside being 5 ft. 3 in., and the total length over buffer beams 12 ft. 11 in. The fuel is carried in bunkers arranged at the sides of the fire-box, and the water in a tank at the trailing end. The boiler is fed by a pair of injectors. The engine with 8-in. cylinders takes a load of about 30 tons up an incline of 1 in 70; those with 9-in. cylinders will draw about 100 tons on the level."

The relative merits of iron and steel have been already so fully discussed, whether for shipbuilding or for boiler-making, that the subject requires no further inquiry (see *ante* p. 231-238.) But a few remarks and illustrations of the details of boiler-construction and the necessary fittings will be desirable.

There are, as we have already pointed out, a great variety of forms of boilers, each adapted for some particular purpose, although generally available for the supply of steam. Boilers are constructed of iron or steel plates, the thickness of which varies according to the form of the boiler, or the pressure to be used. These plates are made to overlap each other at the edges, and are fastened together by rivets or round pins of iron or steel, passed red-hot through holes provided in the plates, and riveted over so as to form a head. A heavy piece of iron is held against the under side of the rivet-head, and the other end of the rivet is struck repeatedly by heavy hammers, and frequently finished by applying a tool hollowed to the shape of the intended head, and striking the tool by the hammers. The rivet, when the operation is complete, is of the form A (Fig. 266) when finished by smart hammering, called *staff-riveting*; and like B when finished by the tool, being then said to be *button-headed.* As the operation of riveting is performed when the rivet is red-hot, not only is the quality of the rivet not impaired by the hammering, as it would be if hammered when cold, but also the contraction or shrinking of the rivet in its length when it cools, draws the edges of the two plates together with great force, and renders the joint impervious to fluid. When it is found by trial that the joints of the plates, or the edges of the rivet-heads, are not quite tight, as manifested by the leakage of water or steam through any of them, a blunt steel chisel or caulking tool is applied to the leaking edge, and struck smartly by a hammer, so as to caulk the joints, or force part of the iron into the crevice.

If we suppose, for instance, that an opening exists between the plates at B, and round the rivet-head at A (shown greatly exaggerated in Fig. 267), the caulking tool applied at the points marked C, forces the iron of the plate edges and of the rivet-heads into the interstices, and thus renders the jointing tight. For jointing the plates at the angles, a peculiar kind of iron, called *angle-iron,* indicated in section A, Fig. 268, is employed; and where there are considerable flat surfaces of plate exposed to bursting, pressure stays, B, are introduced at proper intervals to prevent the plates from being forced asunder.

For fixing the tubes of tubular boilers in the plates through which they pass, holes are first bored or punched in the plates of a proper size to fit the tubes tightly; and the tubes being cut of the proper lengths, and put in their places, the ends are forced open by means of a conical tool driven by hammering into their mouths. Other methods of fixing tubes and stays are employed; and there are numerous other details of boiler-making of a technical character, upon which we need not enter. The furnace or fire-grate of a boiler is generally made of numerous bars of wrought or cast-iron, laid side by side so as to form a grating, on which the fuel is placed, leaving spaces about half an inch wide between the bars for the passage of air upwards to support the combustion, and of the ashes or incombustible refuse downwards into the ash-pit. In front of the bars, there is generally placed a dead-plate or surface without openings, to receive the fresh fuel, which, lying there for some time exposed to the radiation of the fire beyond, parts with a portion of its gases, and is partially coked before it is pushed onwards to the fire-grate. The gases are ignited in their passage over the hot fire, and produce flame, which plays on the surfaces of the flues. When the supply of air is deficient, large volumes of these liberated gases, having numerous particles of carbon suspended in them, pass through the flues without ignition, and thence through the chimney as black smoke. When this happens, not only is a large and valuable part of the fuel wasted, but the air is inconveniently polluted. The object of smoke-consuming apparatus is to prevent this evil; and the general principle on which all such apparatus is constructed, is either to manage the production of these gases in such a continuous regular manner, as that sufficient air may be supplied for their combustion when they are sufficiently heated to ignite, or to supply heated air in some part of the flues, so as to turn into flame there, the gases that would otherwise escape unconsumed; or, finally, when the production of the gases is irregular, to supply air to burn them only at the proper times, and in suitable proportions.

Mud-holes are small holes provided in the lower parts of boilers, and fitted with tight covers, which may be removed, when the boiler is not in use, for the admission of a rake to draw out the mud deposited from the water.

The man-hole, an opening sufficiently large to admit a man, is provided in the upper part of a boiler, and fitted with a tight cover, which may be removed, when the boiler is not in use, for the admission of a man for cleaning or repairs.

Boiler-fittings.—In order to ascertain the water-level within the boiler, several kinds of apparatus are employed. The *float* A (Fig. 269) consists of a stone suspended by a wire passing through the top of the boiler, and connected, by a chain led over a pulley, with a counter-balance, sufficient to balance so much of the weight of the float-stone that it shall always lie at the surface of the water. Should the water-level vary, the position of the float-stone, which rises or falls with it, is marked by an index on the pulley.

Gauge-cocks B C are two stop-cocks fitted into the face of a boiler, one above and the other below the proper water-level. When these cocks are opened, steam should blow through the upper, and water through the lower one. The objection to gauge-cocks consists in the circumstance that, in order by them to ascertain the level, the attendant must open them.

The *glass gauge* consists of two stop-cocks, D and F, fitted in the face of a boiler, one above and the other below the water-line. These cocks are connected by a glass tube E, in which the level of the water is distinctly seen. A stop-cock G is provided at the lower end of the glass tube; and this being occasionally opened, the sediment that may collect in the tube or passages of the cocks is blown out by the pressure within the boiler. Should the glass tube burst, the stop-cocks D and F can be closed until a new tube is fitted, or they can be employed as gauge-cocks.

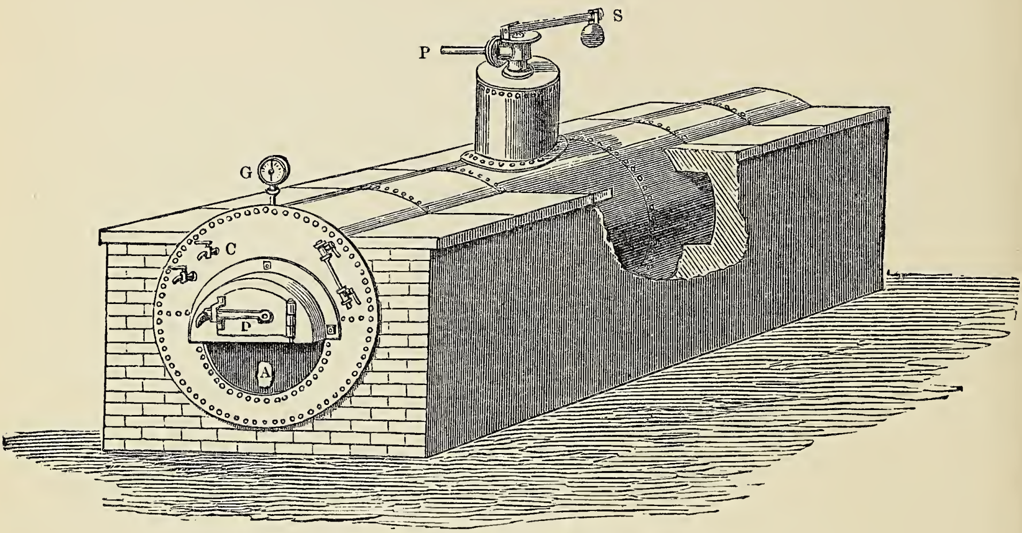


Fig. 262.—A Cornish Boiler.

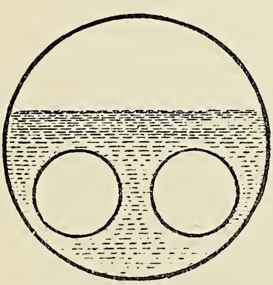


Fig. 263.—The Lancashire Boiler.

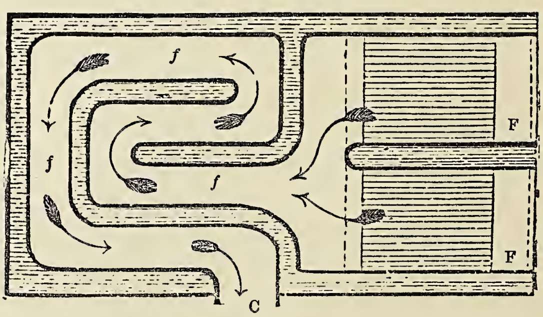


Fig. 264.

Occasionally the float is connected with a whistle, in such a manner that when the level of the water becomes too low, it opens a small stop-cock, which permits steam to blow through the whistle, and thus give audible warning of the danger.

In many-boilers a precaution is taken against

the dangerous consequences of insufficiency of water, by the use of fusible metal plugs. A hole is made in the highest part of the fire-box or flue, which is filled up with a plug or rivet of metal fusible at a temperature not greatly exceeding that of boiling-water. So long as this plug is covered with water, its temperature cannot attain the melting point; but should it be left bare, the heat of the fire playing upon it causes it to melt out, and thus to leave a hole, through which the steam escapes into the flue. Not only does the rush of the escaping steam give warning of the circumstance, but it also relieves the steam-pressure within the boiler, and prevents the explosion which might otherwise result from the over-heating of the flue.

Feeding boilers.—Of course, as the water is

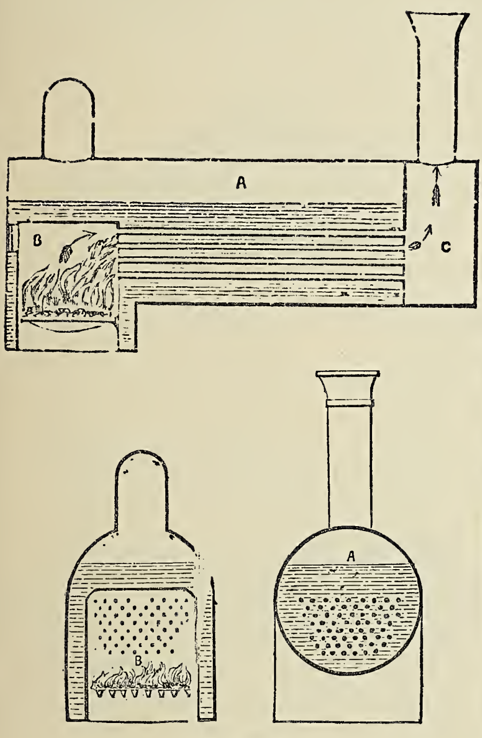


Fig. 265.

converted into steam, and the steam is used by the engine, fresh water must be supplied to keep up the supply of steam, and to ensure the safety of the boiler, the surfaces of which would soon become red-hot, and tend to produce an explosion. In fact, a large proportion of steam-boiler explosions may be traced to a deficient supply of water. In low-pressure boilers, the float occasionally is made to act as a self-feeding apparatus. A (Fig. 270) is a cistern constantly supplied with water, and fitted at bottom with a valve opening downwards into a pipe passing down to nearly the bottom of the boiler; the float B is connected by a wire and lever with the valve, so that when the water-level is too low, the descent of the float causes the valve to open, and thus permits the passage of water from the cistern into the boiler. This arrangement can only be adopted when the pressure of the steam within the boiler does not exceed that of the column of water in the feed-pipe. For high-pressure boilers, the height of cistern and feed-pipe would be inconveniently great to overcome the pressure; accordingly, for these and for marine boilers, the supply of water is effected by means of a force-pump, called the feed-pump, worked by the engine. In this case, as a matter of economy, the water supplied to the boiler is heated, for which purpose, the waste steam of the high pressure engine is employed. Numerous inventions have been patented for thus heating the water. But pumps are constantly liable to be choked by grit, small pieces of coal, &c. This eventually led to the invention of the Injector by Mr. Giffard, of which the following is a description, with an illustration of one of the best forms of this valuable invention.

"The injector is a very convenient and compact form of feeder for boilers of all kinds, whether locomotive, marine, stationary, or portable; this is amply demonstrated by the thousands which are now in use all over the world. A jet of steam forces the feed water into the boiler, and as the injectors will feed a boiler working under even a higher pressure than that from which the jet is taken, the action seems at first sight rather paradoxical. If, however, we remember that the expenditure of steam is about fourteen times the volume of the water injected, and that the same quantity of steam employed in a donkey pump would have easily performed the same work, the result obtained from injectors ceases to be astonishing. The power in a jet of steam is expended in giving momentum to its particles, and it is clear that any apparatus which utilised this power without waste would produce as great an effect as a steam engine. It is essential for the working of injectors that the feed water supplied be not too hot to condense the jet of steam, and it has been found in practice that the temperature of the feed water should never exceed 135° Fahrenheit, and if it does, the injector will not work satisfactorily. Although injectors will draw their water from a considerable distance, it is advisable, if possible, to let the head of the feed water be slightly above the injector. The small sizes of injectors will draw from 2 to 5 feet, and larger up to 15 or 20 feet. Mr. Webb, the eminent engineering-chief of the locomotive department of the London and North Western Railway, has designed and adopted an injector which does not have to draw. Injectors ought to have a continuous supply of dry steam regulated by a valve on the boiler or steam pipe; also a continuous supply of water which should not be hotter than 105° Fahrenheit for low pressure, or 135° for high pressures. There should also be a check or back pressure valve on the delivery pipe."

The general arrangement will be easily understood by inspecting Fig. 271. At the top is the entrance for steam which works the injector. At the top on the left hand side the point of entrance of the water supply is shown, and at the bottom is an opening for the escape of surplus water. On the left is the opening through which the water proceeds to the boiler. The supply is regulated by cocks in the usual manner.

Safety valves.—The forms or various kinds of these are very numerous, because circumstances require modification to special purposes. It is evident that when water contained in a boiler of limited size or strength, and subjected to heat in such a manner as to turn part into steam, exerting unlimited pressure, there would be constant risk of explosion, unless some measures were taken for limiting the force of the steam, and preventing its pressure from exceeding that which the boiler could safely sustain. Every boiler is therefore fitted with one or more safety-valves, which constitute the most important part of the boiler fittings.

The principle of the safety-valve is exceedingly simple. As fluids, and therefore steam, press equally in all directions, any part of the boiler-casing, such as 1 square inch, is subjected to the pressure of the steam. If, then, we make a hole in the upper part of a boiler 1 square inch in area, and cover it with a lid, laying on this lid a weight such as 50 lbs., we can apply heat and generate steam, which, as soon as its pressure exceeds 50 lbs. per square inch, will lift the loaded lid, and permit a portion to escape. Should the generating power of the boiler be moderate, the raising of the lid, and escape of a portion of steam, would prevent the pressure from ever exceeding that due to the weight on the lid; but should the steam be generated more rapidly than it can escape through the hole, the pressure must go on accumulating, until the strain to which it subjects the boiler exceeds the strength of the material of which it

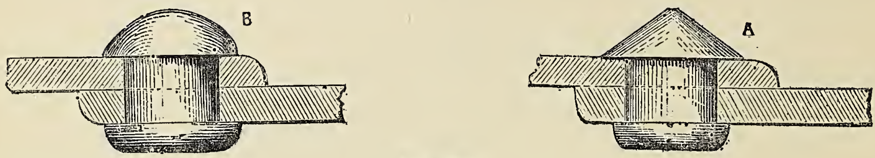


Fig. 265.

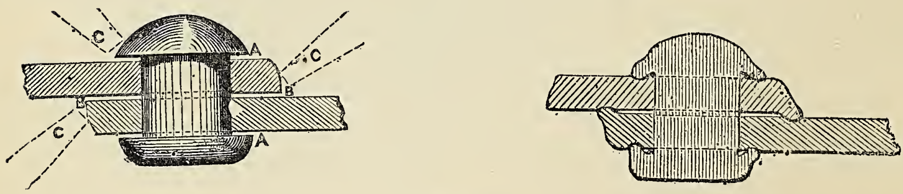


Fig. 267.

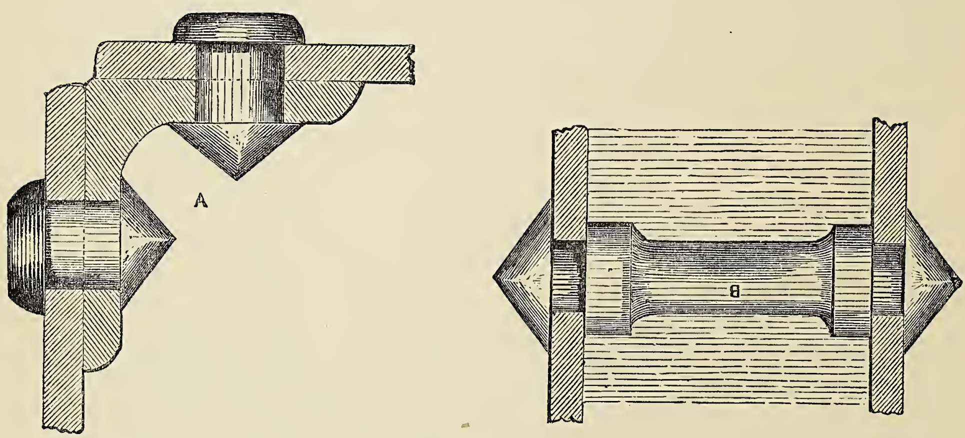


Fig. 268.

is made, and an explosive rupture is the consequence. It is, therefore, important to provide a safety-valve, with an opening of sufficient size to permit the escape of steam as rapidly as it can ever be generated, and to load it with a weight not greater than the pressure which the boiler can safely bear. Boilers are generally tested before use, under a pressure very much greater than that with which they are to be used. For ordinary non-condensing engines, 50 lbs. or 60 lbs. per square inch; and for locomotives, it is as high as 120 lbs. and even 200 lbs. per square inch above that of the atmosphere. The area of the safety-valve should not be less than $\frac{1}{4}$th square inch per horse-power.

Fig. 272 represents a safety-valve of the ordinary construction used for stationary engines. A is a box fixed over a hole B in the upper surface of the boiler, having a truly-faced seating on which the valve C can rest. The stem of the valve passes through the cover of the box, where there is a gland or stuffing-box to prevent

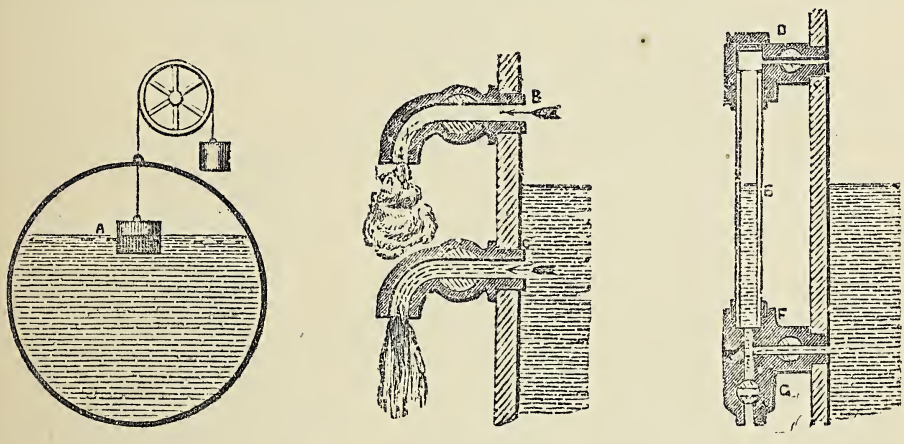


Fig. 269.—Water-gauges for Steam-Boiler.

the escape of steam round the stem. A pipe D conducts the steam that passes the valve, when it is lifted, to the chimney or elsewhere. The valve is kept down by a lever E, which works on a pin, or fulcrum, at F, and has a sliding weight suspended from it at any point such as G. The arm of the lever is graduated so that the weight can be placed to give such pressure on the valve as may be required. If we suppose, for example, that the area of the valve opening is 1 square inch, that the length from the centre of the valve-stem to that of the pin F is 2 inches, and that a weight of 10 lbs. hangs at G, 16 inches from F; then the effect of the weight to press down the stem of the valve is as its weight multiplied by the length of lever at which it acts, divided by the length of lever at which the valve acts; that is to say, the pressure on the valve is $\frac{10 \text{ lbs.} \times 16 \text{ inches}}{2 \text{ inches}} = 80$ lbs. As the area of the valve is 1 square inch, this weight is capable of resisting a steam-pressure of 80 lbs. per square inch within the boiler. If the lever be graduated by divisions each 2 inches in length, each of these will correspond to a pressure of 10 lbs. on the valve; that is to say, the weight at—

16 inches gives a pressure of	80 lbs.	
14 ,, ,, ,,	70 ,,	
12 ,, ,, ,,	60 ,,	and so on.

We have not reckoned the effect of the weight of the valve and lever, which should generally be weighed, so that the pressure due to them, exclusive of the weight, may be estimated before graduating the lever. As a practical example, we will suppose that it is required to make a safety-valve of 4 inches diameter, and load it by a weight and lever graduated to steam-pressures varying from 20 lbs. to 50 lbs. per square inch above atmospheric pressure. We will suppose that the weight of the valve and stem is 5 lbs., that a convenient leverage for the valve is 3 inches, and that the whole lever from F to the end is 30 inches, the lever itself being of uniform depth and thickness, and weighing 9 lbs.

The area of the valve (a circle 4 inches in diameter) is $12\frac{1}{2}$ square inches; the effect of the weight of the lever is the same as if it were collected at its middle point H, 15 inches from F, and its

Pressure on the valve is therefore $\frac{9 \text{ lbs} \times 15 \text{ in.}}{3 \text{ in.}}$
$= 45$ lbs.

To which we add the weight of valve and stem.. .. .. 5 ,,

Making a total constant weight on the valve = ... 50 ,,

And as the area of the valve is $12\frac{1}{2}$ lbs, this gives a constant pressure of $\frac{50}{12\frac{1}{2}} = 4$ lbs. per square inch. For a pressure of 50 lbs. per square inch, or a load of $50 \times 12\frac{1}{2} = 625$ lbs.

on the valve, the additional load must be 575 lbs. at a leverage of 30 inches against that of the valve at 3 inches; and therefore a weight of $57\frac{1}{2}$ lbs. at the end of the lever gives the required pressure; because $\frac{57\frac{1}{2}\text{ lbs.} \times 30}{3} = 575$ lbs. on the valve. The same weight, to give a pressure of 40 lbs. per square inch, should act on the valve with a force of $12\frac{1}{2} \times 40 - 50 = 450$ lbs; and its distance from F must be about 23·48 inches, because $\frac{57\frac{1}{2} \times 23{\cdot}48\text{ inches}}{3} = 450.$

Now the difference between 30 inches, the leverage for 50 lbs., and 23·48 inches, the leverage for 40 lbs., is 6·52 inches—a division that may be repeated along the lever for 30 and 20 respectively.

We might attain the same result by another process, thus:—Since the constant pressure due

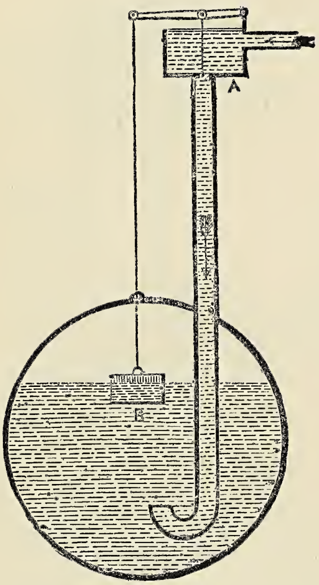


Fig. 270.—Low-pressure Boiler-feed.

to the weight and valve is 4 lbs. per square inch, the additional pressure to be derived from the weight of $57\frac{1}{2}$ lbs., to make a total of 10 lbs. per square inch, would be 6 lbs. per square inch, or $6 \times 12\frac{1}{2} = 75$ lbs. in all. The leverage of the weight to produce this load would be found from the simple proportion:—

Weight.		Load on valve.		Leverage of valve.		Leverage of weight.
$57\frac{1}{2}$ lbs.	:	75	::	3 in.	:	3 913 in.

Repeating the same process for 50 lbs. pressure per square inch, we should find the leverage of the weight to be 30 inches. The difference of 30 inches and 3·913 inches, viz., 26·087 inches, being divided into 40 equal parts, each 0·652 inches—because 40 is the difference between 50 lbs. and 10 lbs.—would mark the lever for each lb. of pressure. Every 10 lbs. would thus be graduated by intervals of $10 + 0{\cdot}652 = 6{\cdot}52$ inches as before.

In locomotives and boilers where a weight sliding along a lever would be inconvenient, the lever is affixed to a spring-balance A (Fig. 273), graduated to the pressures per square inch due to the spring. By turning a nut B on the stem of the spring-balance, any required pressure can be thrown upon the valve, which is kept down by the spring acting on its lever. Should the pressure within the boiler exceed that to which the balance is adjusted, the valve is opened, and a portion of the steam escapes. The lock-up safety-valve consists of a valve pressed down by a set of strong springs C, the whole enclosed within a box under lock and key. While the engine-driver has command over the spring-balance valve, so as to increase or diminish the load at pleasure, the lock-up valve is inaccessible to him, and opens whenever he has loaded the open valve beyond the pressure to which the lock-up valve has been adjusted; thus serving as a check upon him in case of his working at a dangerous pressure.

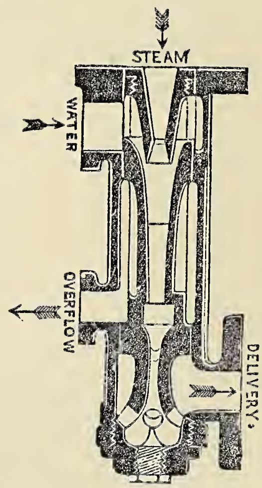


Fig. 271.—The Injector.

In a boiler for an engine working at very low pressures, there is frequently provided a vacuum valve, which is a safety-valve opening inwards, and admitting air into the boiler, in case the pressure within should fall so far below that of the atmosphere without, that there might be danger of collapse.

For marine boilers, in which the rolling of the sea would render the previously described safety valves inadmissible, various modifications of the safety-valve have been invented, into a description of which, however, it would be beyond our present purpose to indulge.

Pressure Gauges.—The steam-gauge is an apparatus generally fitted to boilers for indicating the pressure of the steam. The safety-

valve may be employed for this purpose; for if the weight be adjusted on the lever, or the spring of the balance released, until the valve begins to open and let steam escape, we know that the weight or spring in that condition is a measure of the pressure. But as this mode of

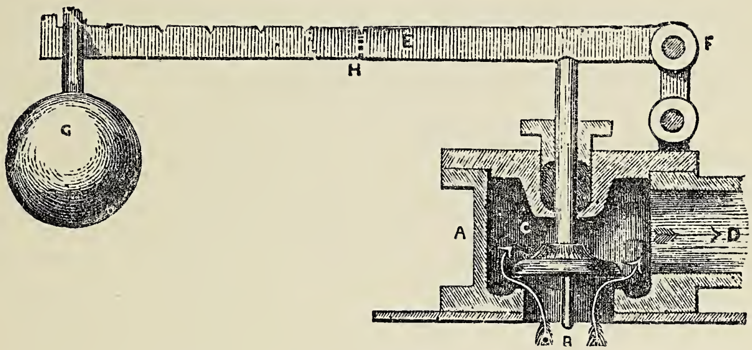


Fig. 272.

measuring the pressure requires personal attendance, it is better to be provided with some self-acting instrument which shall show at a glance the condition of the steam in respect to pressure.

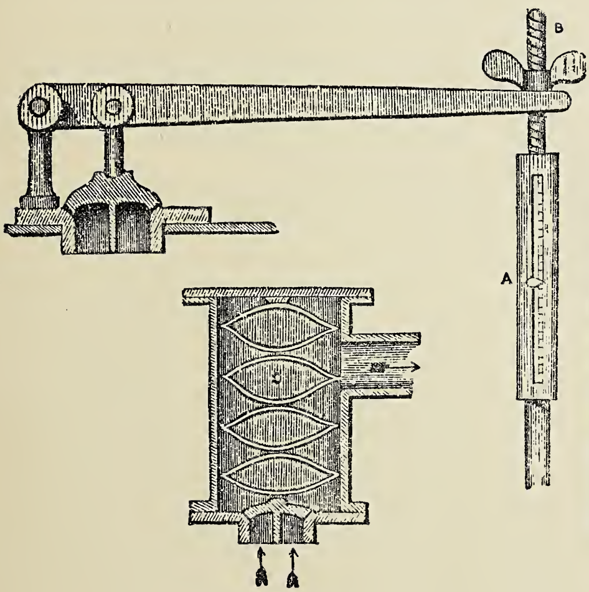


Fig. 273.

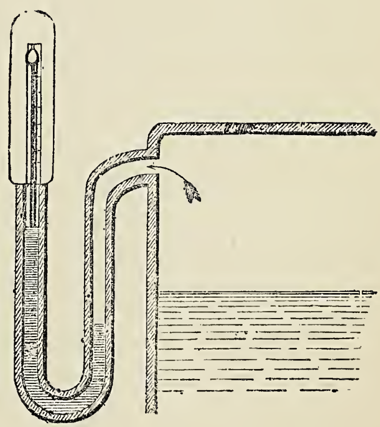


Fig. 274.

For low-pressure boilers, the mercurial steam-gauge is generally employed (Fig. 274). It consists of an iron pipe bent to a syphon form, connected with the boiler, and containing mercury, on which floats a rod of wood extending above the mouth of the tube, and pointing to divisions on a scale. As 2 cubic inches of mercury weigh very nearly 1 lb., the rise of the wooden index through 1 inch in height, indicates that the mercury in one limb of the syphon has risen 1 inch, and fallen 1 inch in the other, making a difference of level of 2 inches, equivalent to a pressure of 1 lb. per square inch in the boiler. Thus every inch on the scale corresponds to 1 lb. pressure per square inch.

For high-pressure boilers, the column of mercury necessary would be inconveniently high, and recourse is therefore had to gauges of other kinds. Among the most effective and ingenious of these may be mentioned that of Bourdon. It consists of a flattened elastic tube of copper

or brass, bent into a spiral form. The pressure within the tube tends to bulge it, and uncoil it a little out of the spiral form; and the slight movement thus induced is communicated to an index, which points on a dial-plate to the pressure marked thereon from the result of experiments made for the purpose of determining the proper graduation of the dial. Illustrations of these gauges will be found at the top front of the pair of Cornish boilers in one of our folio plates, and also at the same position a Cornish boiler represented in its brick setting by Figs. 262, p. 308, *ante*.

The Steam-engine and its various parts.—Hitherto we have chiefly directed attention to the production of steam and the construction of steam-boilers. We now proceed to describe in detail the engine itself in its various parts, their construction and uses so far as the limits of this work will permit.

For the purpose of giving the reader a general view of the various details of the engine, we introduce a representation showing a double cylinder vertical engine and boiler fixed on a baseplate. The engraving and description have been furnished by Messrs. Appleby. In perusing the description carefully the reader will find most of the details of the steam-engine mentioned. Each of these will become the subjects of separate discussion, so that their special object or purpose may be fully understood in relation to each other.

"*The Double-cylinder Vertical Engine and Boiler on Baseplate.*—Fig. 275 is adapted for use in situations where space and cost of erection are important considerations. The cylinders are inverted and are carried on two strong cast-iron A-shaped frames; the slide, valves and boxes being on the outside are readily accessible. The wrought-iron crank shaft is fitted with three wide adjustable gun-metal bearings, and long enough to take a broad strap-pulley outside the fly-wheel and one at the opposite end if desired. A cast-iron cross stretcher connects the two A-frames about midway between the cylinders and the crank shaft, and carries a pair of cast-iron feed pumps with gun-metal boxes and valves; the plungers working in these pumps are a continuation of the piston rods beyond the cross-head, and form the piston rods' guides. The connecting-rods are of wrought-iron forked to miss the pumps, and fitted at each end with gun-metal bearings, wrought-iron straps and cotters. The governors are outside one of the frames, directly over the crank shaft, and are driven by a strap and conicle speed pulleys. The boiler is vertical with two or more cross tubes in the fire box, and fitted with all the usual mountings including safety valves, pressure gauge, glass water gauge, gauge cocks, manhole, mudhole, &c. The engine and boiler are fixed on a cast-iron baseplate, and the whole may be bolted to strong timbers or put down on a bed of masonry or concrete. These engines are sometimes mounted on a cast-iron feed-water tank, especially when a timber foundation is used."

Now all the terms relating to the boiler and its fittings have been already described, but all those which the reader will at once see refer to the engine, it will be now our duty to mention in detail.

Cylinder.—The steam generated in the boiler at such pressure, and in such quantity as may be desired, is conveyed by the steam-pipe to the cylinder, which is a vessel closed at both ends, and fitted with a piston E (Fig. 276), capable of sliding tightly from end to end, and having a rod F passing tightly through one of the end covers, or the cylinder lid, called the piston rod. If we suppose A and B two pipes communicating with the boiler, and opening into the cylinder at opposite ends, while two other pipes, C and D, lead from the ends of the cylinder to the open air, or to any suitable place; conceiving these pipes to be provided with stop-cocks, we can see that by opening A and D, while B and C are closed, we admit steam to press upon the upper surface of the piston E, and force it to the bottom of the cylinder, while the contents of the part below the piston escape by D. On the piston reaching the bottom, if we open B and C, while A and D are closed, the pressure acting on the lower side of the piston forces it upwards, while the steam above escapes. Thus, by alternately opening and closing the four stop-cocks in proper order, an alternating motion is given to the piston, and the force is communicated by the rod to any suitable machinery. The amount of force so communicated depends on the size of the piston, or number of square inches in its surface on which the steam-pressure acts, the intensity of that pressure, and the velocity at which the piston is caused to travel. If we suppose, for instance, that the diameter of the cylinder is 1 foot, the circular area of which is 113 square inches, that the pressure of the steam is 20 lbs. per square inch, and that the average speed of the piston is at the rate of 200 feet per minute, the power communicated through the rod is equivalent to

$$\frac{113 \text{ sq. ins.} \times 20 \text{ lbs} \times 200 \text{ ft.}}{33000} = 13{\cdot}7 \text{ horse-}$$

power.

Some of the first steam-engines had cocks arranged as we have described, which demanded the continual attendance of a workman to close or open them at the proper times. But it suggested itself that apparatus connected to the moving parts of the engine might be so adjusted as to perform this operation; and accordingly great ingenuity has been exhibited in contrivances for alternating the flow of steam.

The Slide-valve.—In the early history of the steam-engine cocks alone were used, as illustrated in the case of Newcomen's engine represented by Fig. 249, at page 300, *ante*. But now the slide is almost universally employed for alternating the flow of steam to or from the ends of the cylinder, except in engines moving very slowly. There are various kinds of slides in use, but they are nearly all contrived on similar principles, with such difference in the details of construction as the peculiar views of the makers or special circumstances require. The most simple form is called the D slide, from the fact that in shape it resembles that letter.

James Watt

Figs. 277 and 278 represent two longitudinal sections of a cylinder fitted with a D-slide. The steam enters by a pipe B from the boiler into a cavity called the *slide-jacket*, on the opposite side of which are three openings, the upper and lower, called the *ports*, communicating by tubes or passages with the upper and lower ends of the cylinder respectively; and the middle one, or exhaust channel, communicating by a cavity E with an opening at the side, by which steam can escape into the open air or the condenser. These three openings are partially covered by a hollowed plate of metal, the *D-slide*, which, as its name implies, can be made to slide up or down by means of a rod C passing tightly through the jacket. The hollowed part of the D-slide is made to embrace the middle exhaust-passage and either of the ports, so as to let steam escape from the cylinder, while it leaves the other port open for the ingress of steam to the cylinder; and as for every ascent and descent of the piston in the cylinder, a corresponding ascent and descent of the slide is effected by means of apparatus connected with the moving parts of the engine, the complete successive alternation of the steam is maintained without the expenditure of more power than is necessary to overcome the friction of the slide over the *facings* in which the ports are situated. The face of the slide, and the surface on which it rubs, are made very true and smooth in the first place; and when they are not subjected to undue wear by the ingress of dirt or grit, their contact remains steam-tight for a long period. The slide we have described is called the short D-slide, and is generally used in locomotives and engines which have not long cylinders. But when the cylinder is of considerable length, the passages from the ports to the ends of the cylinder are also long; and having, at every stroke or alternation of the piston, to be filled with steam, which is ineffective in producing power, considerable loss is occasioned from this waste of steam in merely filling the passages. To obviate this defect, the slide is sometimes lengthened, so that the passages from the ports to the cylinder are proportionally shortened. It is sometimes found convenient for the construction to make this kind of slide of a hollow cylindrical form, fitting into a cylindrical jacket at each end, and being smaller in diameter at the middle. The steam entering at B (Fig. 279) fills the cavity surrounding the slide, and gets access to the cylinder by the upper or lower port as the slide is moved upwards or downwards, while the steam passes from either of these ports into the cavities at the upper or lower ends which communicate through the tubular body of the slide, and from one of which the waste-pipe C conveys the steam which has done its work.

We might mention many other varieties of slides; but all being constructed on similar principles to those we have described, we need not discuss them in detail.

It is unnecessary for our present object to enter any further into a description of the cylinder. We therefore next deal with:—

The Piston.—The piston is constructed in various ways, one of which, being simple and effective, is as follows;—The body of the piston consists of a disc and boss A (Figs. 280 and 281), the outer edge of the disc fitting the cylinder, and the boss having a central conical hole, in which the piston-rod B is secured by means of a key, or thin bar of iron slightly tapered in width, driven through a slot or opening in the boss and rod, so as to tighten the conical end of the rod in the corresponding conical hole. To the body of the piston is secured by screws, a cover C fitting the cylinder, and leaving between it and the edge of the disc below, a groove which contains the packing ring D. This ring is made to fit the cylinder, and is cut obliquely across at some point of its circumference E, a parallelogram-shaped hole being cut out of the middle, and filled with a piece of metal truly fitted to it. By thus cutting the ring across at E, it is permitted to expand in diameter; and the slits made at E are covered by a plate F inside the ring so that no steam can pass by them from one side of the piston to the other. Several bent pieces of steel-plate G are placed between the ring and the boss of the piston, so as to push the circumference of the ring outwards.

As the inside of the cylinder and the edges of the piston and its cover become worn by constant rubbing, the packing-ring is made to expand, and still to work tightly in the cylinder, without permitting the flow of steam past the piston. Sometimes, for small pistons, the packing-ring is merely made thicker at the side opposite its slit; and being at first slightly larger than the cylinder, so that it must be compressed when pushed into it, its own elasticity makes it expand to fit the cylinder even after considerable wear, without the necessity for steel springs within it (Fig. 282).

The piston-rod, in passing through the cylinder cover, is surrounded by a cavity called a stuffing-box and filled with soft twisted hemp and tallow, called *packing*, which is compressed in the cavity by means of a *gland*, forced down upon it by tightening screws. By the use of this packing, while the rod travels upwards and downwards, steam cannot pass round it; for even if the rod be worn somewhat irregularly, the elasticity of the packing serves to prevent the leakage of steam. Occasionally vulcanised india-rubber is employed for the purpose of packing.

The slide-rod, and, indeed, all rods about an engine for moving valves or parts within cavities containing steam or water, have to pass through packing of this kind. In former times the piston was made tight within the cylinder by surrounding it with cotton rope much in the same way that the common ear-syringe is packed. But the piston soon allowed the steam to leak to either end of the cylinder, and consequently great loss of power ensued. The invention of the metallic piston cured this evil. But still a piston will sometimes work unevenly and gradually wear the cylinder into a slightly oblong instead of its original circular form.

This evil has been recently remedied by having *two* piston rods attached to the piston, which, of course, then must always work straight, whether the engine be vertical or horizontal. We are surprised that this idea should have so long laid dormant, as it is so extremely simple and effective.

The *shut-off* and *throttle valves* are mere modifications, differing but slightly from those in ordinary use for water. The *feed-pump* is now much less used than formerly, in consequence of the invention of the *Injector*, described at page 312, *ante*. But still, a brief notice of it may be desirable, as it is still common where boilers and engines of the old type are employed.

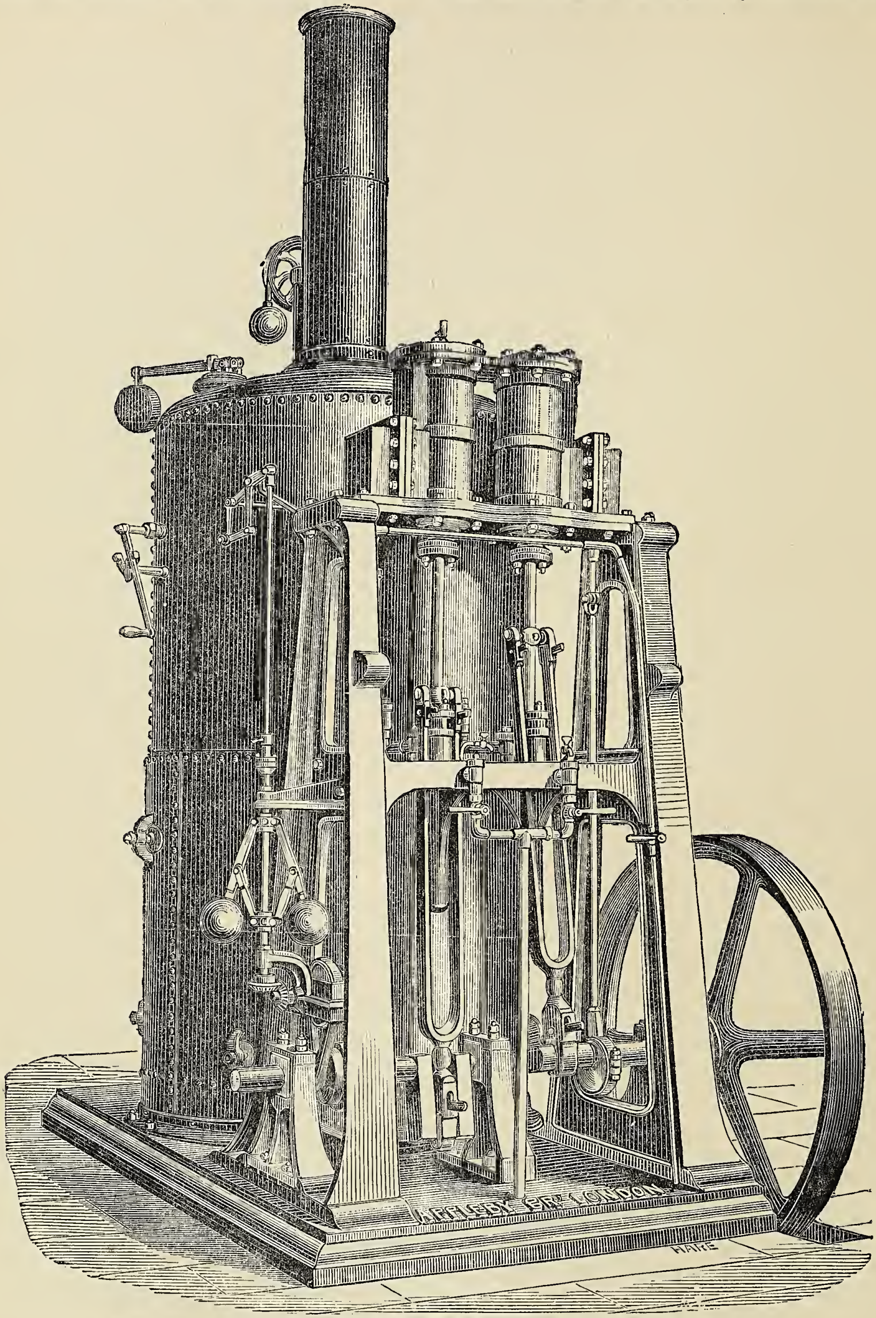


Fig. 275.—Double-cylinder High Pressure Vertical Engine and Boiler.

The feed-pump consists of a barrel C (Fig.

283), in the upper part of which a plunger G is worked alternately upwards and downwards through a stuffing-box. At the lower end of the barrel is a valve-box, containing a suction-valve B, covering a pipe A by which the water is drawn from a convenient reservoir, and a discharge-valve D, past which the water has to flow in its progress to the boiler by the feed-pipe E. When the plunger is raised, the valve D being

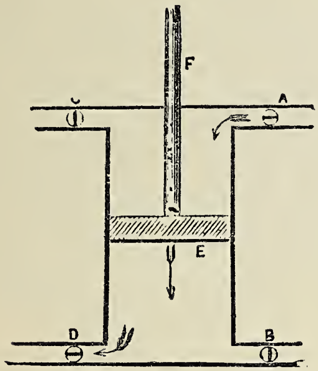


Fig. 276.—The Cylinder.

down the valve B, but raises the valve D, and flows onwards to the boiler. At some convenient part of the feed-pipe E there is always fitted a stop-cock, or shut-off valve, for completely cutting off communication between the pump and the boiler in case of the valves being deranged. But water

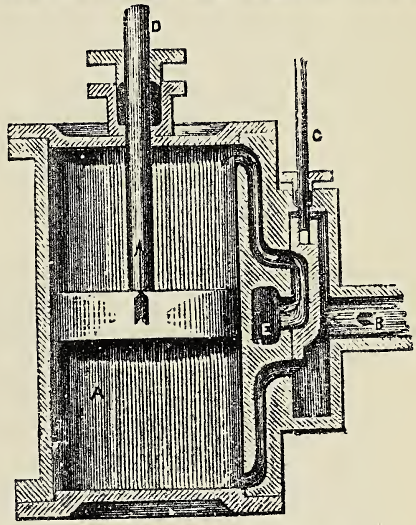


Fig. 278.—The D Slide.

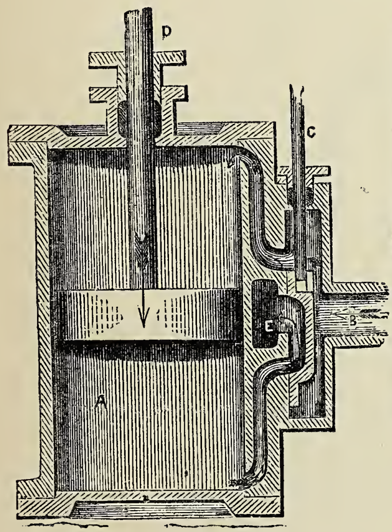


Fig. 277.—The D Slide.

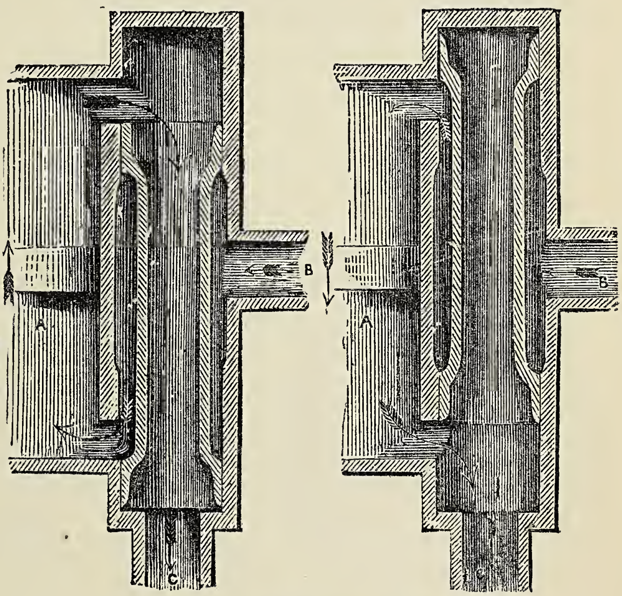


Fig. 279.—The Long D Slide.

kept down in its seat by the pressure of water in the boiler (equivalent to that of the steam) communicated through the feed-pipe E, the vacuum left by the rise of the plunger is filled by water entering from A and raising the valve B for its passage. On the descent of the plunger, the water being forced out of the barrel, presses

being almost totally incompressible, it would be extremely hazardous to close this communication while the pump is in action; for in that case the barrel must be burst open, or some part of the machinery that works the pump must be broken. It is, therefore, usual to provide also a relief valve, constructed exactly like a safety-

valve on the feed-pipe, to permit the efflux of the water when its ordinary passage is closed. The cover F of the feed-valve box should be capable of being readily moved to give access to onwards to the boiler while the plunger ascends. In all cases, indeed, where water under considerable pressure is exposed to the recurring action of a propelling force, as in the feed-pump,

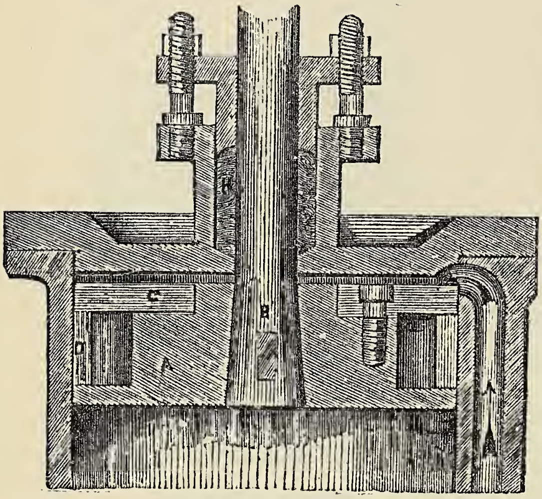


Fig. 280.—The Piston and Piston-rod.

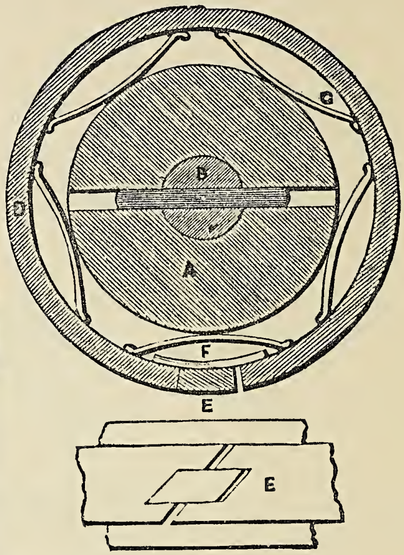


Fig. 281.—Packing-ring of a Piston.

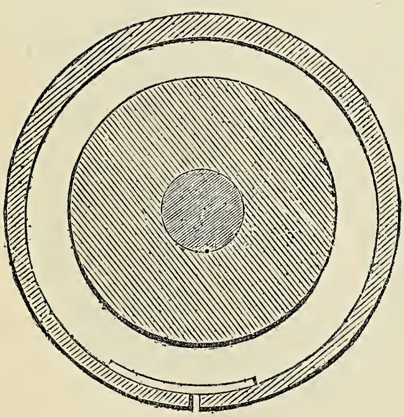


Fig. 282.—Metallic Ring of a Piston.

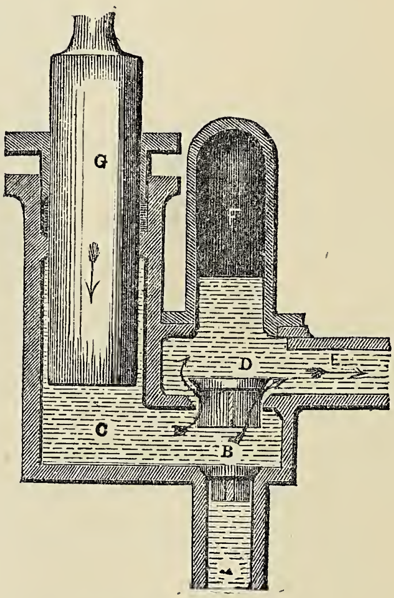


Fig. 283.—Feed-pump.

the valves ; and it is often made of considerable size, hollowed out to contain air, which is compressed by the influx of water during the descent of the plunger, and reacts to force the water an air-vessel should be provided to act as a spring, relieving the blow on the water, and regulating its motion to a gradual flow instead of a sudden movement.

Those of our readers who have employed feed-pumps will have an adequate idea of the annoyances they often produce. Unless the valve B (Fig. 283) accurately fits into its seat, the pump will not deliver the expected amount of water, and consequently, if the regularity of the pump be trusted to, without constant reference to the gauge-cocks or gauge-glasses already described at page 308, *ante*, the most serious results may follow. In fact, a defective or out-of-order feed-pump has been the cause of many boiler explosions.

We next turn to consider how the up and down motion of the piston in the cylinder is converted into a circular motion in the usual form of all kinds of steam-engines.

Crank and Connecting Rod.—We have hitherto chiefly traced, so far as the construction of the steam-engine goes, the production of what may be termed for the sake of simplicity—an up-and-down motion,—that is, the rising and falling of the piston in the cylinder. There is, perhaps, no other purpose to which such a motion as that could be applied except that of pumping, and even then it would be far from economical and convenient. We have, therefore, now to inquire how this so-called reciprocating motion of the piston can be converted into a rotatory movement for the purpose of driving machinery, and how, at the same time the various parts of the engine itself shall be simultaneously worked to maintain its necessary movements either alternately or continuously.

For this purpose a crank and connecting rod are in the first place necessary, and the following will afford an adequate description of their various parts and their working.

To the end A (Fig. 284) of the piston-rod there is jointed the connecting-rod A B, having an eye at B working on the *crank-pin*, or pin fixed to the *crank*—an arm B C projecting from the main shaft or spindle C. The crank-pin can move round in a circle, the diameter of which is exactly equal to the length of stroke, or distance through which the piston travels in the cylinder. As the piston descends from F to G, making the down-stroke, the crank is caused to revolve from E round to D or one half-revolution. Again, while the piston ascends from G to F, making the upstroke, the crank revolves from D round to E, another half-revolution. Each revolution, then, of the crank requires a double stroke of the piston ; and to effect it, the upper and lower portions of the cylinder have each to filled and emptied of steam ; or, as their capacities are equal, the cylinder has for each revolution to be twice filled and emptied. It is obvious that, at every different point of its revolution, the crank is acted on by a different force, owing to the varying obliquity of the connecting-rod. At the two extreme points, D and E, where the crank is in a line with the connecting-rod, the effect of the piston to cause it to revolve is reduced to nothing ; for it merely pushes or pulls it against the central shaft. These points are technically called the *dead centres*, because there the force of the piston is dead or ineffective. But to make up for the total want of action at those points, we find that at some other points the effect of the force passing

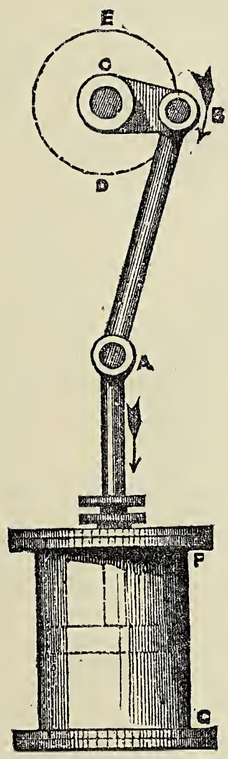


Fig. 284.—Crank and Connecting Rod.

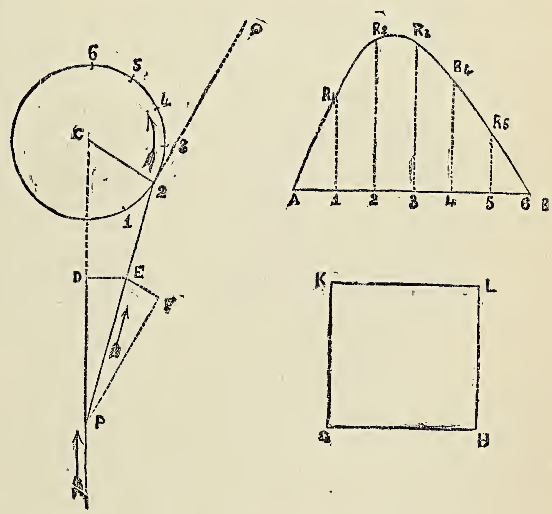


Fig. 285.

through the connecting-rod to turn the crank, is greater than the pressure on the piston, in consequence of the obliquity of its action.

Again, the piston, during a revolution or double stroke, passes through a distance equivalent to twice the diameter of the crank-circle; while the crank-pin passes over the circumference of that circle, more than 3 times its diameter. The influence of the pressure on the piston to turn the crank may be best conceived a line 2 P representing the connecting-rod, and draw Q 2 touching the circle at 2, and therefore representing the direction in which the crank-pin is moving at the point 2, while the line P C represents the direction of the piston, we may take any length P D in that line representing the force of the piston (as, for instance, if the pressure on the piston were 5 tons, we might take P D=5 inches), draw D E perpendicular to P D, P F parallel to Q 2, and E F perpendicular

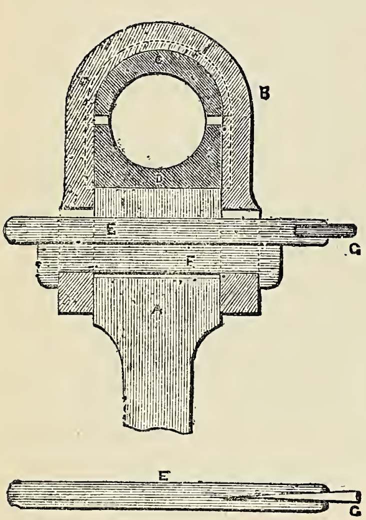


Fig. 286.

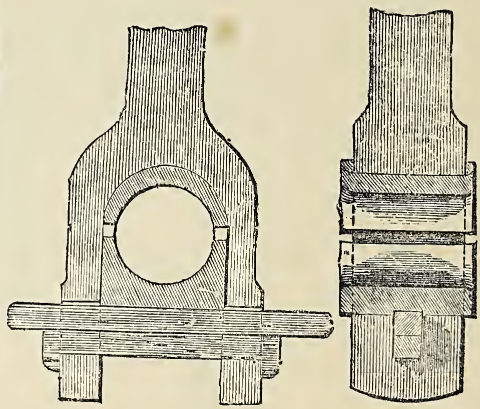


Fig. 287.

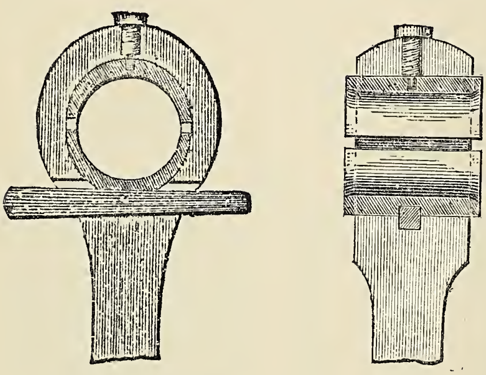


Fig. 288.

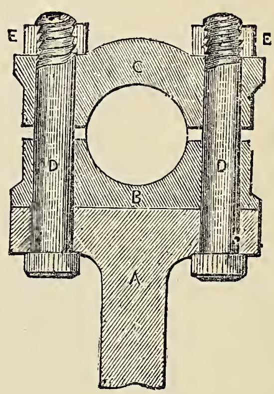


Fig. 289.

by a graphical delineation of the force in the following manner:—If we divide the circle described by the crank pin round the centre C into any number of equal parts (Fig. 285), and draw a straight line A B equal to the half-circumference divided into corresponding parts, A B represents the distance through which the crank-pin moves during half a revolution, developed into a straight line. If at any point, such as 2, we draw a line 2 C representing the crank, and to P F, or parallel to C 2. Then, on the principle of resolved forces, the length of P E represents the force transmitted through the connecting-rod, and P F the force tending to turn the crank, while D E measures the side thrust on the piston-rod, and E F the longitudinal strain on the crank, pushing the shaft against its bearings. If, now, at the point 2 in the line A B we erect a perpendicular 2 R_2 equal in length to P F, and at the points 1, 3, 4, &c.,

erect others deduced by the same kind of construction, we can trace a curve through their summits, the height or ordinate of which at any point measures the force turning the crank-pin at the corresponding point of its circumference; and therefore the area or space enclosed between the curve and its base A B, which may be considered to be made up of an indefinite number of these ordinates, measures the total force expended on the crank during a half-revolution. If, now, we take a line G H equal to the diameter of the crank-circle or the stroke of the piston, and, dividing it into any number of equal parts, erect ordinates each equal to P D, and therefore representing the constant force of the piston, the area of the rectangular figure G H K L thus formed will, in like manner, measure the total force of the piston during one stroke. It will be found that the area of this figure is exactly equal to that of the curvilinear figure, as might be predicted from the knowledge of the *universal* mechanical principle, that by no combination of machinery can we create or annihilate force; and that consequently, whatever power the piston during its straight stroke impressed upon the crank, is found in the crank during its circular movement. By altering the length of the connecting-rod, as compared with that of the crank, we alter the figure of the *force-curve*, but we do not change its area; and whether the connecting-rod be long or short, the power conveyed through it during the half-revolution is the same. The other half-revolution being effected under similar circumstances, would give a *force-curve* precisely like that of the former.

In this investigation we have observed that the oblique action of the connecting-rod causes a lateral thrust on the piston-rod, measured by the line D E. It will be found, that the longer the connecting-rod, the less will this lateral thrust be; and as it is a force not only useless to the machinery, but positively prejudicial, tending to bend the piston-rod or force it out of its straight path, it is advantageous to reduce it to as small a quantity as possible, and to provide means for counteracting its influence. For this reason, a long connecting-rod, three or four times the length of the crank radius at least, should be employed, and the end of the piston-rod should be made to move in guides so as to prevent it from being deflected. We have already noticed, however, another method of preventing this evil. It is that of having two piston-rods instead of one.

As the piston at the dead centres has no influence in causing the crank to revolve, it is necessary to provide some means of making up for this deficiency. On the crank shaft there is fixed a large heavy wheel called the *Fly-wheel*, which revolves with it, and acts as a reservoir of force to carry the crank round the dead centres, and otherwise to equalise the movement. A large mass of matter, such as the fly-wheel, weighing sometimes many tons, cannot be put in motion at a high velocity without the expenditure of great force; but when it is in motion it requires as great force to arrest it. In the motion of a crank connected with a fly-wheel, while the crank is receiving its most advantageous impulse from the piston at such points as 2, 3 or 4, it communicates some of its overplus to the fly-wheel, which is there stored up in the form of momentum or active power, to be given out upon the crank and any machinery connected with it, when, at the points 1 and 6, it is receiving no power from the piston.

In cases where a fly-wheel, on account of its

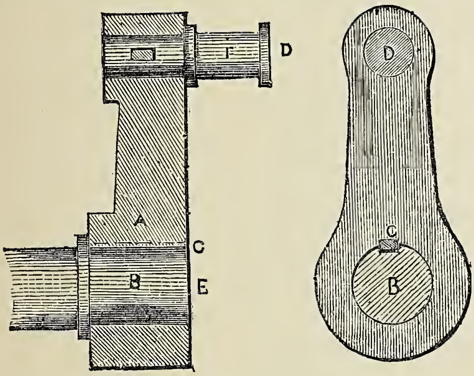


Fig. 290.—The Crank.

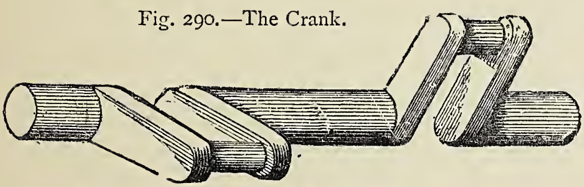


Fig. 291.—Two Cranks on one Shaft.

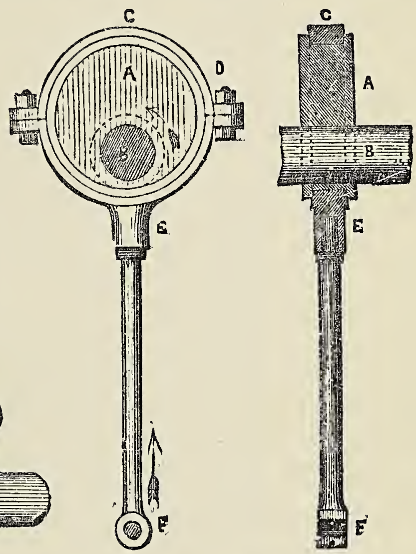


Fig. 292.—The Eccentric.

weight and bulk, cannot be applied—as in marine and locomotive engines—the engine is made in duplicate, with two cylinders, pistons, connecting-rods, and cranks, both of the cranks being fixed on one shaft at right angles to each other. While the one crank is on its dead centre, and receiving no rotatory impulse, the other crank is nearly at its best position for receiving the force of its piston, being at right angles with the first-named.

As the whole power of an engine has to pass through its connecting-rod, the joints which connect it with the piston-rod and the crank require to be made of great strength, and with precautions against friction and wear. The pins of the crank and piston-rod, on which these joints work, are made of wrought-iron or steel, for the sake of strength; and as the friction of like metals upon each other is found to exceed that of different metals, the eyes at the ends of the connecting-rod are lined or *bushed* with brass, gun-metal, or some soft metal, such as tin alloyed with copper. The special construction of those eyes depends upon circumstances, different engineers having preferences for different forms.

In Fig. 286, is represented what is called the *strap-eye*. The end A of the connecting-rod is squared, so that a wrought-iron strap B, bent to horse-shoe form, can slide on to it. Between the arch of the strap and the flat end of the rod are inserted the upper brass C and the lower brass D, generally made of gun-metal, sometimes lined with soft metal. The brasses have projecting lips or flanges at each side to prevent them from moving sideways within the eye. Through the sides of the strap and the head of the connecting-rod is cut a slot, into which are fitted two pieces of iron, the *key* E and the *gib* F, each slightly tapered, so that when the key is driven gently into its place by a hammer, it acts as a wedge, pulling the strap down and thereby tightening the brasses on the pin to which they are fitted. A little space is left between the edges of the brasses to permit their closer approach as they or the pin become worn in the hole; and the slot for receiving the gib and the key is extended upwards in the strap and downwards in the connecting-rod, to permit the key to be driven. Lest the key should be shaken loose by the motion of the machinery, it is often split open at the small end, and a wedge G is driven in to spread it laterally.

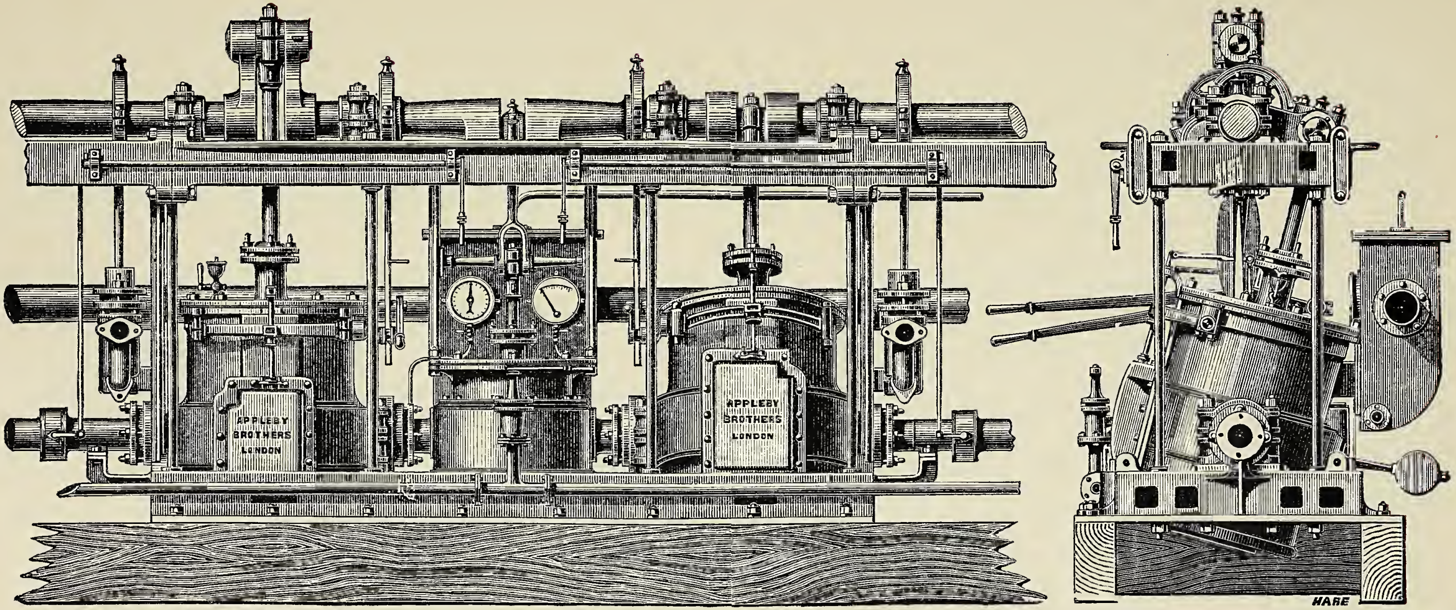
The fork-end (Fig. 287), is made by forming the end of the connecting-rod like a fork, fitting it with gun-metal bushes, and tightening them by means of a gib and key.

The bushed-eye (Fig. 288), is formed by shaping the end of the rod into an eye, in which gun-metal bushes are fitted, capable of being tightened by a key passing through a slot in the rod, and bearing against the lower bush.

Sometimes the eyes are made as represented in Fig. 289. The end of the rod A is spread out to form a flat face, on which are fitted two brasses made with a hole to fit the pin, and secured by means of bolts and nuts D, E, passing through holes in the end of the rod, and in the brasses fitted accurately to receive them.

Such are the modes principally used in forming the eyes of connecting rods, or of any joints through which considerable strain has to be communicated. The crank A (Fig. 290), is made, sometimes, of cast-iron for stationary engines, but, generally, for marine engines, of wrought iron, having a hole fitted to B the round end of the shaft, on which it is fixed, and prevented from turning by a key C, or tapered piece of iron, driven tightly into a slit, formed partly in the crank, and partly in the shaft. Generally, the round hole in the crank is made slightly smaller in diameter than the round end of the shaft; the crank is heated so as to expand it, and permit it to be driven on the shaft; and as it cools it tends to contract, and thereby becomes very firmly bound on to the shaft, the end of which is riveted or hammered over the hole. The crank-pin D is made to fit truly into a hole in the crank, in which it is sometimes secured by a key or pin driven through it transversely. The distance E F, between the centre line or axis of the shaft and that of the pin, is called the *throw* of the crank, and it is exactly half the length of the *stroke* of the piston. For locomotive engines, and, indeed, for many of the largest marine engines, where double cranks are required, it is usual to forge both cranks and the shaft in one piece, as indicated in Fig. 291. By this means great strength and simplicity are secured, and all the risk of the loosening of parts, put together by keys or otherwise, is avoided.

The Eccentric.—As, by means of a crank, the reciprocating motion of a piston is converted into a continuous rotary motion of the shaft, so the continuous revolution of the shaft may, by means of a crank, be converted into a reciprocating movement for the slide or feed-pump; but for this purpose, instead of a crank, an eccentric is generally employed. It consists of a circular disc A (Fig. 292), having a hole B, *not* in its centre, through which the shaft passes. Round the disc is fitted a ring C, generally made in halves, secured to each other by bolts and nuts at D; and to one side of the ring is attached the eccentric-rod E F. The eccentric disc, or *sheave,* being firmly fixed on the shaft, is caused to revolve with the latter, and its centre is thus made to describe a circle round the centre of the shaft. The whole sheave thus becomes a crank-pin of extended diameter; and as it can slip freely round within the ring, the end F of the eccentric-rod is caused to move upwards and downwards, during every revolution, through a distance equal to the diameter of the circle through which the centre of the sheave revolves. The radius of this circle is called the *throw* of the eccentric; and its diameter, or the distance through which F is caused to move during a half-revolution, is called the *stroke* of the eccentric-rod. The setting of the eccentric upon the shaft, or the fixing of its position with respect to that of the crank, is a matter of nice adjustment for causing an engine to act well, as we shall endeavour to describe. Let A (Fig. 293) represent the outline of a cylinder and piston, with the ports at one side, and a long D-slide D fitted to them; C the circle in which the crank-pin



OSCILLATING ENGINES, FOR USE IN STEAM VESSELS.

revolves, and E that in which the centre of the eccentric revolves in connection with it. We suppose the piston at the top stroke, and the crank-pin at C. If it be intended that the crank shall revolve in the direction of the arrow in 1, the eccentric revolving in the same direction, the slide should be just opening to admit steam above the piston, and to permit its exit from below it. The centre of the eccentric must, therefore, be at some such position as E′—so that, as it continues to revolve, it may continue to open the slide to steam above and to eduction below for some time, and then be ready at e' when the crank reaches C′ to reverse the movement. Again, if the rotation of the crank be jecting from its face, and a piece, or stop, C D projecting from the shaft. When the shaft moves in one direction, the eccentric remains at rest until the end C of the stop comes against B, when it is caused to revolve with the shaft. But, if the shaft rotate in the opposite direction, it leaves the eccentric behind, until D comes round to A, when it is again caused to revolve, but having its centre changed with respect to any fixed point on the shaft, by a quantity determined by the extent of slip before the opposite edges of the stops come in contact. When this arrangement is adopted, the end of the eccentric-rod is generally made of the form indicated in Fig. 295, having what is called a *gab* or round-

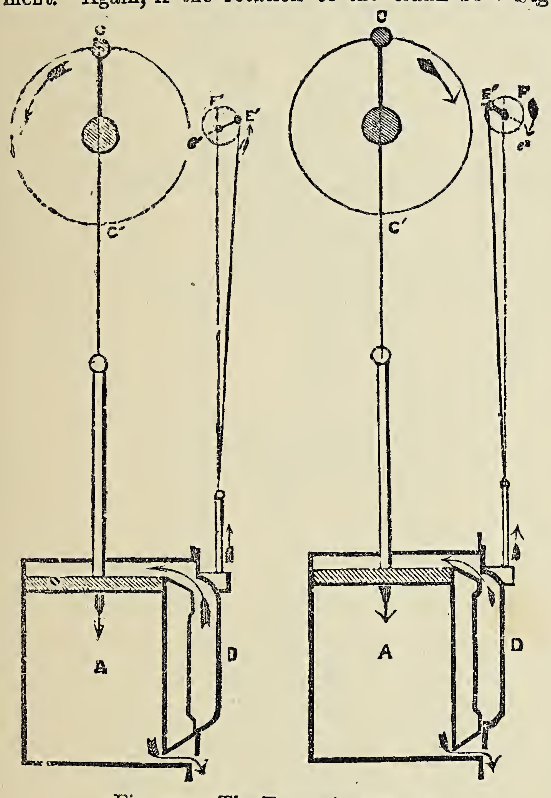


Fig. 293.—The Eccentric at Work.

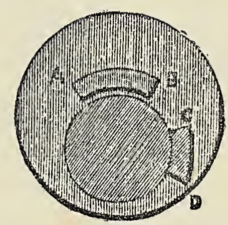


Fig. 294.

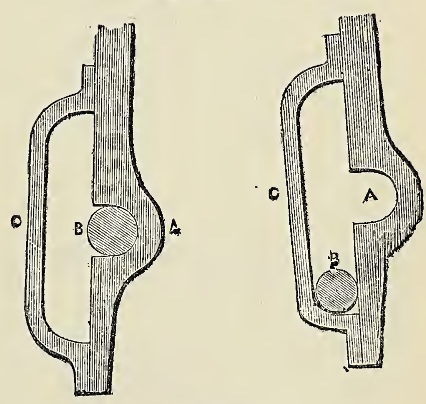


Fig. 295.

in the opposite direction, as in 2, the eccentric centre must for the like reason be at E″, a point on the side of the vertical central line opposite to that occupied by E′. In an engine always moving in one direction, the eccentric can be fixed on the shaft in such a manner as to give the proper movement to the slide; but when it is desired that the engine should move in the opposite direction some expedient must be devised for altering the position of the eccentric on the shaft through an angle measured by twice E′ F′, or E″ F″, so as to throw its centre as much to one side as it was to the other side of the crank-pin. The simplest mode of effecting this object is to make the eccentric sheave loose on the shaft, with a piece A B (Fig. 294) projecting from its face, and a piece, or stop, C D

bottomed notch A fitted to the pin of the slide-rod B. When the eccentric-rod is pushed or drawn aside, so as to relieve the slide-rod pin from the gab, the slide can be moved upwards or downwards by hand, independently of any motion of the eccentric-rod, and the movement of the steam above or below the piston thus changed at pleasure. C is a guard or stop to prevent the withdrawal of the rod too far from the pin. The slide-rod is generally made capable of being worked by a lever conveniently situated for the hand of the attendant. When he wishes to reverse the motion of the engine, he quickly withdraws the gab from the slide-rod pin, and by means of the hand-lever moves the slide in the direction opposite to that in which it was

formerly moved by the eccentric. He thus throws the steam-pressure on the opposite side of the piston—if it were formerly ascending, it begins to descend, and conversely—the movement of the crank and shaft, is thus reversed; the stop that drives the eccentric is brought round to the opposite side; and when, after a few alternations of the slide by hand, the reversal of the engine is fairly established, the gab of the eccentric-rod is permitted again to levers worked for a time by hand; while great care is demanded on the part of the attendant, lest he work them in such a way as to neutralise each other, or oppose the reversing effect which he desires to produce. To overcome these difficulties, an ingenious arrangement, called the *link motion*, has been introduced in marine and locomotive engines. For each of the engines there are two eccentrics fixed side by side on the shaft, and their rods are jointed to an arc A

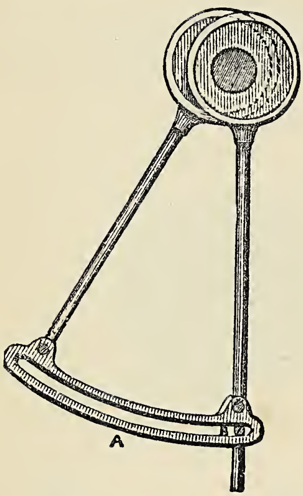


Fig. 296.—Eccentric with Link Motion.

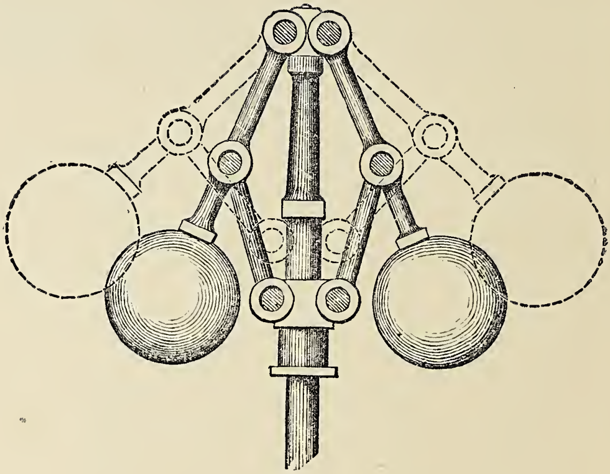


Fig. 297.—The Steam-engine Governor.

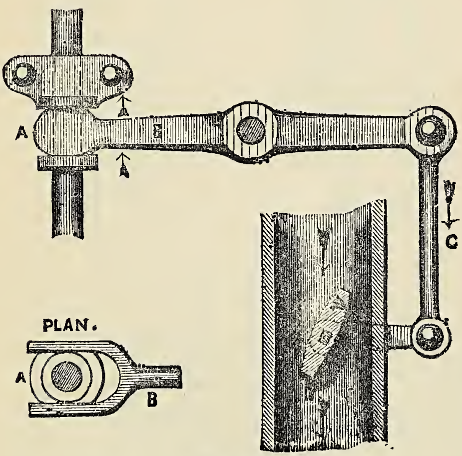


Fig. 298.

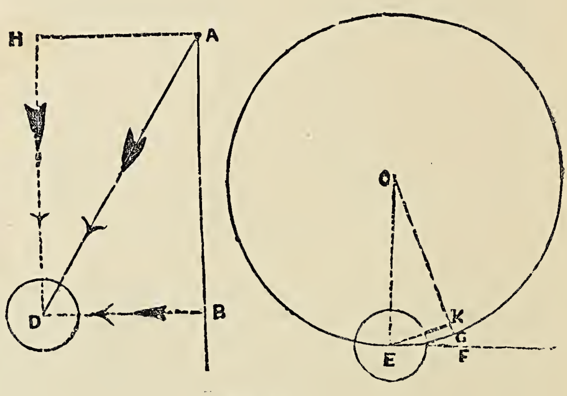


Fig. 299.

drop over the slide-rod pin, and the contrary motion continues.

When there are two engines working together, such as marine or locomotive engines, the number of operations required for reversal makes it a rather difficult matter. There are two slides, two eccentrics, and two sets of hand levers; both gabs have to be thrown out of gear, and both (Fig. 296), with a circular slot in it, in which the pin B of the slide-rod can freely slide. The two eccentrics are fixed on the shaft in such positions that one is adapted for the motion of the shaft in one direction, while the other suits its motion in the opposite direction. When the rod of the one is nearly in a direct line with the slide-rod, it gives it its reciprocating motion,

while the other merely causes the arc to oscillate without affecting the motion of the slide; but when the arc and rods are pulled aside, so as to bring the slide pin under the other eccentric rod, its motion is given to the slide, and the engine is thus reversed. With such an apparatus, then, one simple movement of a hand-lever, connected with the arcs of both engines, causes their immediate reversal. But this is not the only advantage of the link motion. It will be readily seen that the middle point A of the arc being brought round to the slide-rod pin, the latter will be left nearly at rest; for the opposite ends of the arc being moved nearly in opposite directions by the eccentrics, will merely oscillate round A, as a fulcrum or centre. By bringing the arc to this position the engines are stopped, because the slide being at rest, admits no alternation of steam above or below the piston. Again, by shifting the arc so as to bring the pin to any point on either side of A, more or less movement of the slide in either direction is produced at pleasure, and thus the quantity of steam passing through the ports into the cylinder may be varied, and consequently the speed of the engine, according as the slide is caused to expose a greater or less amount of opening at the ports for its admission.

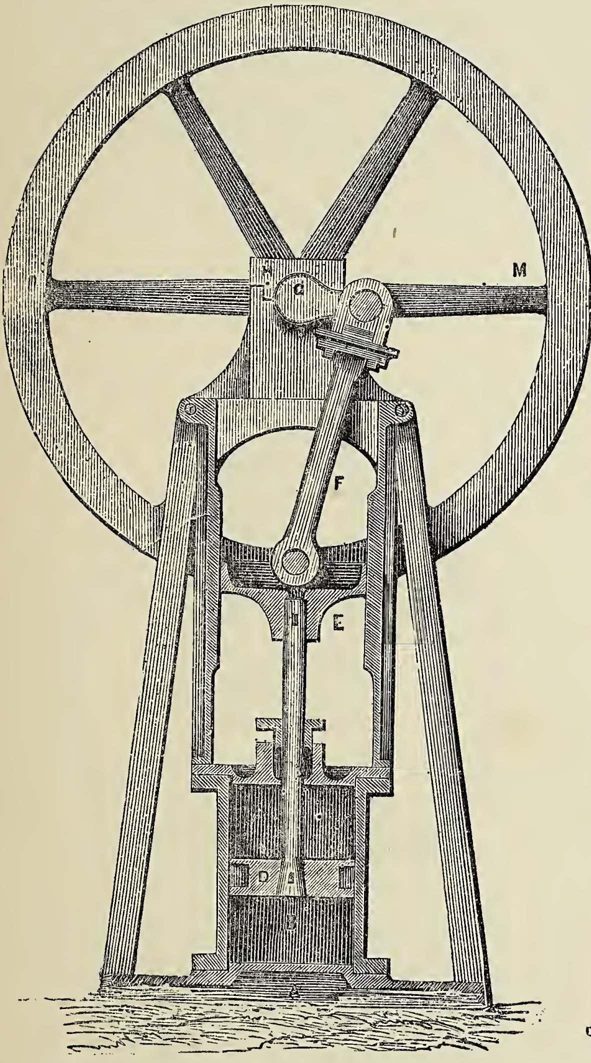


Fig. 300.—Vertical High Pressure Engine.

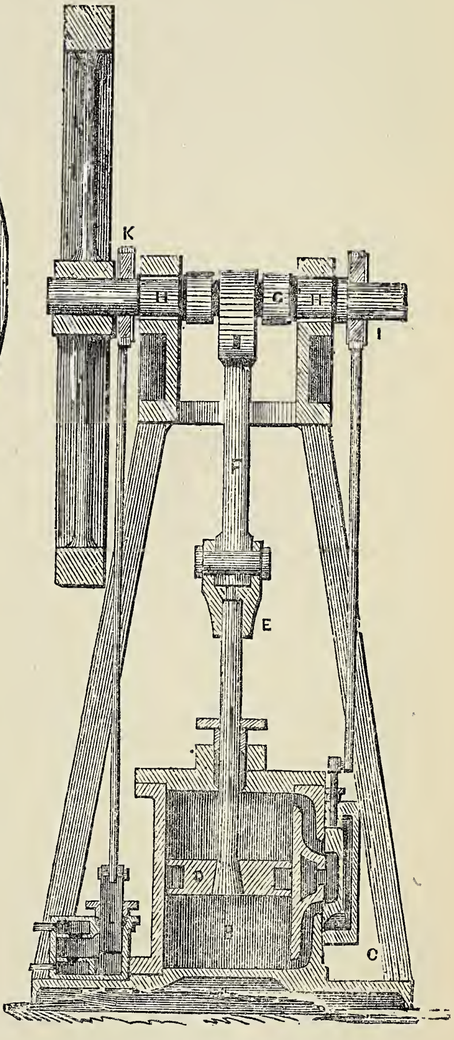


Fig. 301.—Section of the Engine.

The Governor.—In marine and locomotive engines, which are always under the immediate control of the engineer, any irregularity of motion, in respect to speed, is of little importance. As regards marine engines the water acting on the paddles, or on the screw-propeller,

acts as a kind of brake on the speed of the engine; equally so does the friction of the rails in that of the locomotive. But in respect to stationary engines, used, for example, in spinning textile articles, no such brake exists. If a few machines are suddenly turned off, the power they used is sent to the remainder in motion, and their speed is unduly accelerated. Occasionally, when many machines are thus suddenly thrown off, the engine acquires a dangerous speed, called "racing," which may, and does frequently end in the fly-wheel being broken to pieces, producing disastrous and fatal results to property and life. The best apparatus (although still by no means perfect) is the Governor, which was invented by the celebrated James Watt. The apparatus is represented in Fig. 297.

the arms that carry the balls must be regulated by the speed at which they revolve. In discussing this question, we need only consider one ball, as each is regulated by the same law, and they are generally made in duplicate for the sake of balancing the apparatus, and to give it symmetry. The force which tends to throw the ball outwards from the vertical spindle, is the centrifugal force of its revolution, or its tendency in obedience to the first law of motion to proceed in the straight line E F (Fig. 299), touching the circle in which it revolves, rather than to be continually diverted from its straight to a circular path. The force which opposes the centrifugal force, and causes the ball to be continually deflected from the straight line, is the weight of the ball tending to push it close home to the vertical spindle. If we take any position of the ball,

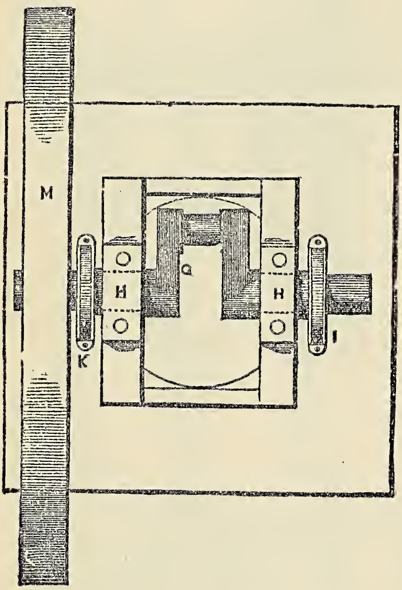


Fig 302.—Plan of the Engine.

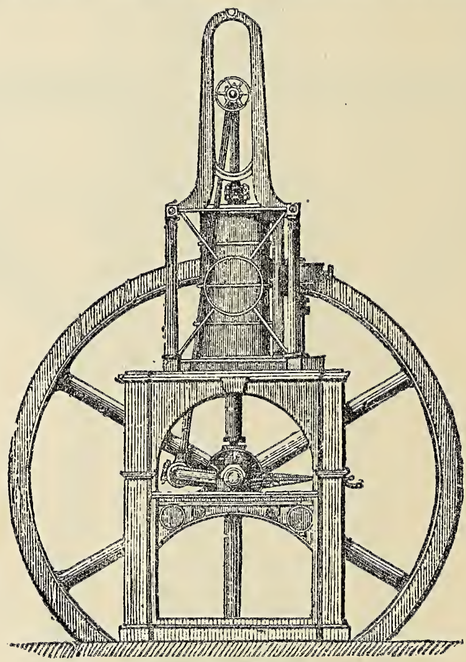


Fig. 303.—The Table Engine.

A vertical spindle is put in motion by the engine, and revolves quickly or slowly, according to the velocity of the engine. When it revolves rapidly, the balls fly outwards, and raise the grooved brass which slides on the spindle A (Fig. 298), and thus moves a forked lever B, which, by proper rods and levers C, causes the throttle-valve D to turn round in the steam-pipe, and check the passage of the steam to the cylinder. When the engine revolves slowly, on the other hand, the balls fall in, the brass sinks, and the throttle-valve is presented edgeways to the steam, and permits a more free passage.

As, in the pendulum of a clock, the length from the point of suspension to the bob must be regulated to beat seconds, or half seconds, or any other intervals that may be required; so in the conical pendulum or governor, the length of

such as D, A B being the vertical spindle, and complete the parallelogram of forces A B D H, while the line D H or A B represents in quantity and direction the weight of the ball, drawing it down, and D B or A H the centrifugal force pushing it outwards, A D represents the resultant of those two forces as a tension on the rod by which the ball is suspended. If we know the velocity with which the ball moves in its path, and the radius of that path, we can estimate its centrifugal force in comparison with its weight, and can make the limb A D of such a length that these two forces shall be properly proportioned for a certain velocity.

The length of the arm of the governor, measured from the point of suspension to the centre of the ball, may be found from the following rule :—

Divide 200 by the number of revolutions per minute, and multiply the quotient by itself for the length in inches.

Example.—Required the length of a governor arm suited to 50 revolutions per minute:

$$\frac{200}{50} = 4, \text{ and } 4 \times 4 = 16 \text{ inches.}$$

To find the speed suited to a governor of a given length of arm.

Divide 200 by the square root of the length (in inches), and the quotient will be the number of revolutions per minute.

Example.—Required the proper speed for a governor having an arm 16 inches long.

The square root of 16 is 4, and $\frac{200}{4} = 50$ revolutions per minute.

The rods and levers connecting the governor with the throttle-valve should be capable of adjustment, and it is useful to have an adjusting counterbalance to the centrifugal force of the balls, by changing which, the regulated speed of the engine can be varied at pleasure. Although the governor we have described is a most valuable accession to an engine, yet it is not a perfect regulator; for its very mode of action implies that the velocity of the engine must have undergone a change, before the governor can have begun to act on the throttle-valve. But within certain limits, the variation in speed of an engine thus regulated is inconsiderable, and there is no apparatus so simple and durable that is capable of maintaining like regularity. Other contrivances for governing the speed of engines have been applied with a certain amount of success, but our space will not permit us to enter into a description of them.

Having thus described the principal fittings, parts, &c., of a high pressure engine, we next turn to discuss some of the forms in which that kind of engine has been employed.

We have already given, at page 316 *ante*, an illustration of a vertical engine and boiler constructed for a variety of purposes, and others will come under our notice.

Direct-Acting Engines.—Figs. 300 and 301 are sections, transverse to each other, of a vertical, direct-acting non-condensing engine; and Fig. 302 a plan of the same. A is the foundation-plate, forming the bottom of the cylinder B, which is secured to it by bolts and nuts. C, the slide and steam passages. D, the piston and rod, terminating in a cross-head E, which works between guides, and to which is jointed the connecting-rod F. G, the crank; and H H, the bearings in which the crank-shaft revolves. I, the eccentric and rod for working the slide; and K, an eccentric for working the feed-pump L. M, the fly-wheel. This engine is of very simple construction, and has no parts that are unnecessary to its efficient working.

Fig. 303 gives a view of what is called a table-engine. The cylinder is elevated on a table; the piston-rod terminates in a cross-head, having a roller at each end working in a guide, and a connecting-rod descending on each side of the cylinder to a shaft made with two cranks below, working in bearings, and carrying a fly-wheel and eccentrics for the slide and feed-pump. The governor is driven by bevil gearing from the crank-shaft.

High pressure engines are made of almost every possible form to adapt them to certain purposes. In the folio plates will be found representations of engines of a portable kind used for agricultural purposes, which will become more specially under notice when we enter on the subject of Agriculture. Traction engines, also represented in the folio plates, are largely used for drawing heavy loads on common roads. Cranes, lifts, &c., already represented and described in our previous pages, are frequently worked by high pressure steam engines. In fact, throughout this work they will come constantly under our notice.

In Fig. 304 is represented a horizontal high pressure engine, as constructed by Messrs. Appleby, of London, and used for a variety of purposes. In this engine the centre line of the cylinder is kept as near to the top of the bed-plate as possible in order to ensure stability, and all the working parts are easy of access; the whole is mounted on a strong cast-iron bedplate, and bolts are provided for securing it to a foundation of stone, brickwork, or timber.

The cylinder is of hard grey metal accurately bored, and has turned flanges and bright covers, metallic piston fitted with wide cast-iron split ring, steel springs and gun-metal tongues; the piston rod is of steel, working through a stuffing box of ample length, and is firmly cottered into the crosshead which is got up bright.

The connecting-rod is of hammered scrap iron turned and shaped bright, and both ends are fitted with wrought iron straps, gun-metal bearings and adjusting keys. The guide blocks are of ample length, and work between two pairs of guide bars, the lower bar of each pair being planed to form an oil trough. The feed-pump has gun-metal valves and valve box, and is of ample dimensions for feeding the boiler. The crank shaft is of hammered scrap iron turned bright, and carries a heavy cast-iron fly-wheel; it is also left long enough to take the strap pulleys or gear required for transmitting the power of the engine. The disc plate is of cast iron, turned on the face and edges, and is firmly keyed to this shaft by a sunk steel key. The slide valve is planed and scraped on the face, and is fitted with a steel spindle, and driven by a cast-iron eccentric with gun-metal strap and wrought-iron rod. The speed of the engine is regulated by a throttle valve and low-speed governors, but a Porter's or other high-speed governor can be employed.

An engine of a similar type forms the subject of one of the folio plates in this work.

Oscillating Engines. — Before quitting this portion of our subject, we may refer to a particular form of engine, which has been largely adopted where economy of weight and of space is desirable:—we mean oscillating engines. At first these were made on a small scale suited for such boats as those which ply on the Thames;

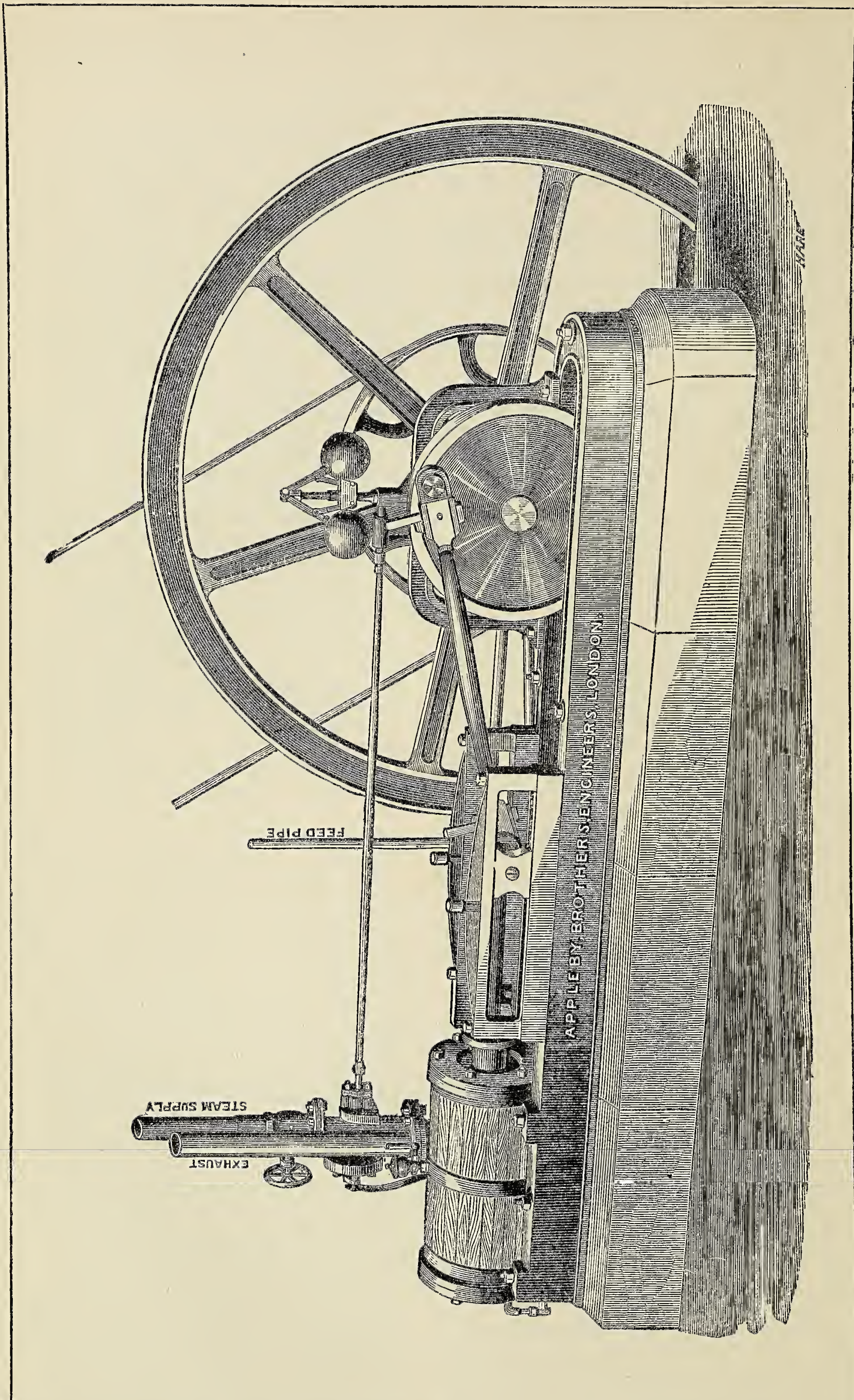


Fig. 394.—Horizontal High Pressure Engine.

but of late years they have been employed on a very large scale, and with success. The paddle-engines of the "Great Eastern" were of this kind, and many other large vessels are now fitted with engines of like construction. The cylinder of an oscillating engine, instead of being fixed firmly on its bed, is provided with trunnions at each side, about midway in its length, somewhat like those of a cannon, and these trunnions are fitted into bearings formed in the framing, in such a manner that the cylinder is free to oscillate upon them as on pivots. The piston-rod which passes through a long and strong stuffing-box on the cylinder cover, is made of larger diameter than usual, for the sake of giving it great strength transversely; and it is jointed directly on to the crank without any intervening connecting-rod. As the crank-pin travels round in a circle, it carries with it the top end of the piston-rod, not only in a direction upwards and downwards, (co-incident with the axis of the cylinder), but also from side to side (or transversely to the axis). The motion of the piston, from end to end of the cylinder, accords with the one direction of the crank's motion, and the oscillation of the cylinder on its trunnions allows for the other. As the steam has to be admitted to the oscillating cylinder, and has also to escape from it after having done its work, the trunnions are made hollow, and form passages for the steam to and from a jacket or steam space provided on the cylinder, whence it passes by suitable ports, commanded by a slide, to and from the opposite ends of the cylinder successively. For several years after the invention of this arrangement, it remained comparatively idle, because of the mechanical difficulties that were experienced in properly working the slide on an oscillating cylinder, itself oscillating with it. At length an ingenious arrangement for overcoming these difficulties suggested itself, and shortly afterwards the use of oscilliating cylinders became very general on the small scale, and gradually came to be adopted for the very largest marine engines. One of the folio plates of this work illustrates a pair of oscillating engines for use in steam vessels, but the type is also employed for stationary purposes.

In many instances the ordinary high pressure engine can be converted partly into a condensing engine, of which we shall have presently to speak, by some ingenious contrivances. Of this nature is the *Evaporative surface condenser*, patented and constructed by Messrs. Appleby to whom we are indebted for the following description and the above illustration.

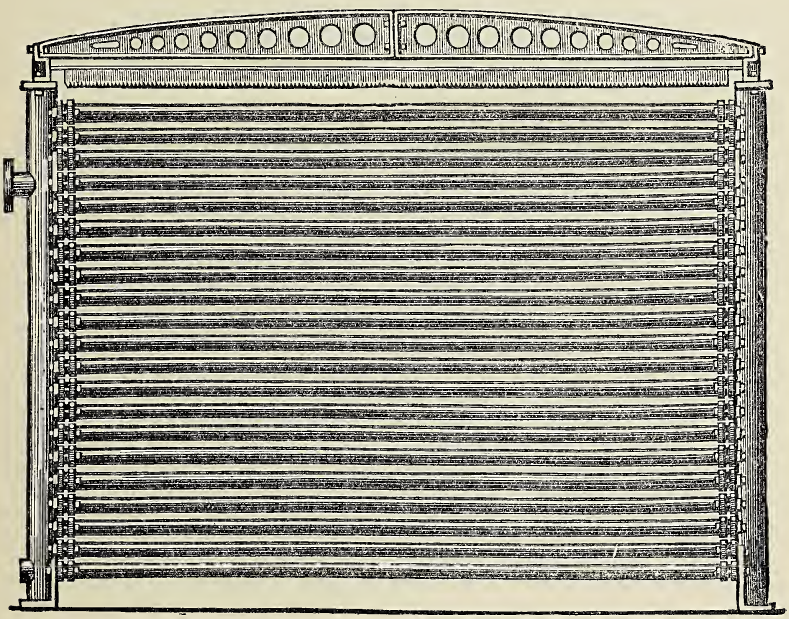


Fig. 305.—The Evaporative Surface Condenser.

"*Patent Evaporative Surface Condenser.*—Fig. 305. This system is invaluable where the supply of water is limited or costly, a good vacuum being maintained with a consumption of water which is altogether unattainable by any other method of condensation. These conditions exist in London and in many large towns, as well as in all countries where water suitable for feeding boilers is scarce, and fuel expensive. We have carefully tested the apparatus at our own works in London, where we have applied it to a single-cylinder horizontal engine; the condenser has been at work for some time, and the saving in fuel has been at least twenty per cent. This is sufficiently important in itself; but there is the further

great advantage that the scale on the boiler, which formerly caused great inconvenience, has almost entirely disappeared. The construction is remarkably simple, and the absence of any element liable to derangement renders this system of condensation specially valuable in isolated places in connection with steam engines, vacuum pans, &c.

"The condenser consists of a number of copper tubes with cast-iron boxes at each end, and a copper trough with serrated edges at the top, as shown in the engraving. The steam to be condensed is admitted into the cast-iron boxes, and spreading through the copper pipes the condensation is effected by a shower of water flowing over the serrated edges of the copper trough and trickling down over the exterior of the pipes. Thus the condensing water is converted into steam, and absorbs not only its proportion of sensible heat, but also some latent heat, producing at least five times greater effect than is obtained by injection. The water lost by evaporation outside the tubes is only equal to that produced by the condensation of the steam within them, and the consumption of water is but little more than is required for an ordinary high-pressure engine of equal power, because the condensed water is returned to the boiler in a heated state, and so is used again. The apparatus may be at a considerable distance from the engine, and the more exposed the situation the better the result obtained, the atmosphere assisting to some extent to maintain the vacuum. The data required for estimating the size and cost of the condenser required is furnished by an indicator diagram, or if that cannot be obtained it will be necessary to give—

"The temperature of steam as it leaves the cylinder, or the initial pressure and point of cut-off.

"The diameter, length of stroke, and number of revolutions made by the engine.

"The position of the condenser relatively with the engines.

"These condensers may be applied to almost any existing high-pressure engine, or a number of engines may be connected to one set of condensers: in the latter case a group of cast-iron pipes, fixed vertically, gives a very excellent result, but the quantity of condensing water required is larger than if thin copper pipes of small diameter are used."

We must refer our readers to works specially treating on the steam-engine for the discussion of the use of the indicator and dynamometer in calculating the power of any and all forms of the steam-engine; but the following remarks may be useful as giving a very near approximation to the truth in calculating the power of an ordinary high-pressure engine.

We assume the engine to be in fair working order, and fitted with an ordinary slide, cutting off the steam at about $\frac{2}{3}$rds of the stroke; that the steam-pipe is not of great length, and well clothed with non-conducting material; that the ports are well-proportioned, and the piston and slide tight. We farther suppose the piston to travel at the velocity of 200 feet per minute, which is found to be practically a fair working rate; and that a horse-power, to be effective, after all allowances for friction, &c., should be estimated at 44,000 lbs. moved 1 foot per minute, or 220 lbs. moved 200 feet per minute. We observe the pressure in the boiler, and deduct from it $\frac{1}{4}$th for loss by cooling in the steam-pipe and expansion in the cylinder, and 2 lbs. for resistance to exit and other losses, the remainder being reckoned as the mean effective pressure. Multiplying this by the area of the piston, and dividing by 220, we get a fair estimate of the power.

Example.—An engine having a cylinder 30 inches in diameter, is worked at a pressure of 36 lbs. in the boiler; required its power.

From pressure in boiler		36 lbs.
Deduct one-fourth for cooling, &c.	9 lbs.	
And for back pressure . . .	2 lbs.	—11 ,,
Mean effective pressure		25
Multiply by area of 30 inches . . .		707
Divide by		220)17675
Horse-power		80

In general it is the business of engineers to provide engines of certain powers without special reference to the pressure at which they should be worked. By employing very high pressures, the size, weight, and cost of an engine are certainly reduced; but, on the other hand, some danger is incurred, and the tear and wear are considerable. By using very low pressures, again, the cylinder must be large, the engine is generally cumbrous and heavy, and little advantage can be taken of the expansive power of the steam. We consider a boiler pressure of 40 to 50 lbs. to be a fair average on which to estimate the engine-power; and would suggest the following rules for calculating the power of a given engine, and the diameter of cylinder necessary to produce a given power.

1. To find the power of an engine when the diameter of the cylinder is given.

Rule.—Divide the diameter (in inches) by 3, and square it for the horse-power.

Example.—Required the power of an engine having a cylinder 15 inches in diameter.

$$\frac{15}{3} = 5, \text{ and } 5 \times 5 = 25 \text{ horse-power.}$$

2. To find the diameter of cylinder necessary for a given power.

Rule.—Multiply the square root of the power by 3; the product is the diameter of the cylinder in inches.

Example.—What should be the diameter of a cylinder for 100 horse-power?

Square root of 100 = 10, and 3 × 10 = 30 inches.

The length of stroke must depend on the number of revolutions made by the crank in a given time. It is convenient to assume that the piston, in engines going at a fair average speed, shall travel over 200 feet per minute. Sometimes it moves at the rate of 250, and even exceeding 300 feet per minute; but, upon the

whole, 200 is a convenient and economical speed. This is the product of twice the stroke by the number of revolutions; and hence its half, 100, is the product of the stroke by the number of revolutions. If, then, either the length of stroke or the number of revolutions be given, the other may readily be thus found:—

1. Given the length of stroke to find the speed.

Rule.—Divide 100 by the stroke (in feet), the quotient is the number of revolutions per minute.

Example.—What is the speed of an engine having 2 feet 6 inches stroke?

$$\frac{100}{2\frac{1}{2}\text{ feet}} = 40 \text{ revolutions per minute.}$$

2. Given the speed to find the stroke.

Rule.—Divide 100 by the number of revolutions per minute, the quotient is the length of stroke in feet.

Example.—What must be the stroke of an engine making 35 revolutions per minute?

$$\frac{100}{35} = 2{\cdot}86 \text{ feet, or about 2 ft. 10 ins.}$$

With respect to the condensing engine our remarks will be confined simply to the principle points in which it essentially differs from the high-pressure engine which has already been fully described. In all main points the two agree, but the condensing engine requires additional arrangements in order that a vacuum produced by condensing the steam may be employed as a source of additional power. In fact, this is occasionally done in respect to the high-pressure engine by condensers, such as are described and illustrated at page 329, *ante*.

If we suppose that the steam, on leaving the bottom of the cylinder, instead of flowing out into the atmosphere, which resists its egress with a force of 15 lbs. per square inch, were conducted into a vessel totally devoid of air or steam, this resisting force could be entirely removed, and the effect of the steam pressing on the upper side of the piston would be increased by that quantity. If the vacuum in the vessel were not perfect—that is to say, if there were contained in it some rare fluid, such as air or steam, or a mixture of both, greatly attenuated, and capable of pressing with a force of only 2 or 3 lbs. on the square inch—the pressure of the steam on the piston would be increased by the quantity of 2 or 3 lbs. less than 15 lbs. per square inch. Generally, if we reckon the pressure of steam in the boiler as its absolute pressure, not its excess over that of the atmosphere, and deduct the pressure of fluid in the vacuum vessel, the difference will be the effective pressure on the piston. Thus, with steam in the cylinder exerting a pressure of 10 lbs. above that of the atmosphere, or having an absolute pressure of 25 lbs. per square inch, while the vacuum vessel contains a fluid pressing with a force of 2 lbs. per square inch, the effective pressure on the piston will be 25—2 = 23 lbs. per square inch. The condition of the fluid in the vacuum vessel, as to pressure, is generally measured by a barometer. But vacuum gauges are also employed, which are constructed on similar principles to the pressure-gauges of Bourdon and others already described, only that they show the *absence* instead of the presence of pressure within the condenser.

It is evident, therefore, that the condensing engine chiefly differs from the non-condensing or high-pressure engine in the fact that it requires a condenser and air-pump, the condenser to convert the used steam into water and the air-pump to remove any air in the condenser so as to make the vacuum as complete as possible.

The Condenser and Air-pump.—The condenser is a vessel B (Fig. 306), generally made of about $\frac{1}{4}$th of the capacity of the steam-cylinder, with which it communicates by the pipe D. The steam, after acting on the piston, instead of escaping into the atmosphere as in non-condensing engines, flows by this pipe into the condenser, which is placed in a cistern of cold water, and has a pipe and cock, I, for the admission of a jet of cold water to condense the steam. This jet is called the *injection*, and its quantity is regulated by means of the cock, worked by a rod passing upwards, with a handle in some place convenient for the attendant. The bottom of the condenser communicates by a passage, having a valve G, with the air-pump A. The bucket or piston P of the air-pump is fitted with valves opening upwards, and is moved upwards and downwards by a rod connected with some reciprocating part of the engine, and passing through a stuffing-box in the air-pump cover. Near the top of the air-pump there is a passage Q, fitted with a discharge valve opening into the *hot-well* K, from which the feed-water is pumped to the boiler, the overplus or waste being discharged by a waste-pipe. The cistern in which the condenser and air-pump are placed. is kept constantly filled with cold water by a pump called the *cold-water pump*, supplying it by a pipe N at the bottom, while the heated water overflows by a suitable waste-pipe. While the steam from the cylinder flows into the cold condenser, and meets the cold water diffused through it by the injection jet, it becomes condensed into water, and falls with the injection-water to the bottom, occupying very little volume compared with that which it occupied while in the state of steam, and leaving the space of the condenser as a partial vacuum. But water always contains a quantity of air mingled with it, which passes over with the steam from the boiler to the cylinder, and thence to the condenser, and the injection-water also parts with a portion of the air it contains, so that after a time the condenser would become filled with the air so liberated, and with the water of injection and condensation, unless means were taken to remove them.

As the air-pump bucket descends, the discharge-valve Q being closed, no air or water can enter from above to fill the space left void by the descent of the bucket, but the air and water from the condenser pass through the valves G and P, and enter this space from below. On the ascent of the bucket, the bucket-

valves P being closed by the pressure of air and water above them, the contents of the pump are discharged through the valves Q into the hot well. Thus by the alternate descent and ascent of the air-pump bucket, when its capacity and the amount of injection are properly proportioned, almost a perfect vacuum is maintained in the condenser; and the effective pressure of the steam on every square inch of the piston is increased by nearly 15 lbs. above that which it would be, were the steam permitted to escape uncondensed into the atmosphere.

The condenser is generally fitted with a *blow-valve* H, which comes into play on starting the engine. The engine having been stopped, the condenser and air-pump may have become quite filled with water through the injection-cock; and on starting the engine again, no vacuum could be produced while they are thus *water-logged*. But by opening a small valve called the *blow-through valve*, a communication is made between the steam-pipe from the boiler, and the eduction-pipe leading from the cylinder to the condenser. The pressure of the steam in the boiler is thus brought to bear on the water in the condenser, and forces it out by the *blow-valve* H, the steam occupying its place. On shutting the blow-through valve and opening the injection-cock, the steam in the condenser is condensed, and a vacuum formed, so that the engine may be started. As long as there is even a partial vacuum in the condenser, the atmospheric pressure on the blow-valve keeps it closed.

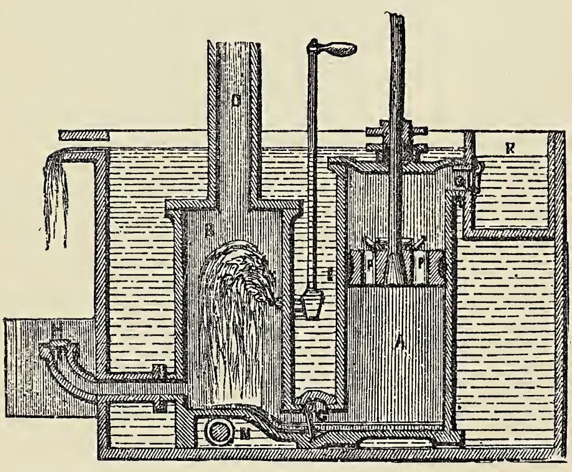


Fig. 306.—The Condenser and Air-pump.

The bottom-valve, bucket-valves, and discharge-valves of the air pump, are frequently made of vulcanised caoutchouc sheet, cut into discs and laid over gratings. Water or air forced through the perforations in the gratings, raises the flexible discs of caoutchouc, and passes round their edges; but neither air nor water can return, for the atmospheric pressure forces the caoutchouc discs firmly down on the gratings, and thereby effectually closes their openings.

Injection Water.—It is a peculiar property of all vapours, that, besides their sensible heat, or the temperature to which they raise the thermometer, they contain a great amount of latent heat, not measured by the thermometer, but by its effect, when the condition of the vapour is changed. The latent heat of steam, when its temperature or sensible heat is 212°, is estimated to be about 1,000°. This does not mean that the latent heat could raise a thermometer 1,000°, but simply that a pound of steam at 212° being condensed by its mixture with 1,000 lbs. of water at any temperature, such as 60°, could raise the temperature of the whole mass of water 1°. In other words, if it were found that the combustion of a certain weight of fuel could raise the temperature of a given mass of water from 211° to 212°, it would require 1,000 times that quantity of fuel to convert the water into steam, having still the sensible temperature of 212°. This great latent heat is something essential to the condition of water in a state of vapour; for as soon as any portion of it is removed, by bringing the steam into contact with a cold substance, a part of the steam is immediately condensed into water; and the remainder, expanding to fill the space thus left void, loses density and pressure as it gains volume. In estimating the quantity of injection-water necessary for condensing the steam of an engine, we must therefore bear in mind that it is not alone the sensible temperature, but also the latent heat of the steam which we have to absorb by the cold water injected. Let us assume that 1 cubic foot of water, having been converted into steam in the boiler, and having acted on the piston in the cylinder, flows into the condenser at a temperature of 212°, and containing 1,000° of latent heat, and that it there mingles with a quantity of water at 62°, sufficient to condense it and produce an ultimate temperature of 112° throughout the mixture. The total heat of the steam being 1,212°, has to be reduced to 112°—that is, the steam has to lose 1,100° of temperature; the injection-water entering at 62°, and being raised to 112°, has to gain 50°. The quantity of injection-water must therefore be 22 cubic feet; for 22 cubic feet raised 50°, are equivalent to 1 cubic foot reduced 1,100°, because $22 \times 50 = 1,100$.

The temperatures we have assumed are such as would frequently occur in practice; and generally it will be found that the quantity of injection-water required for an engine is from 15 to 25 times the quantity erquired for feed.

The capacity of the air-pump is generally $\frac{1}{8}$th of that of the cylinder, the stroke being usually $\frac{1}{2}$, and the diameter $\frac{1}{2}$ that of the cylinder. The power necessary to work the air-pump of a

condensing engine is about $\frac{1}{10}$th of the total power.

The Surface-Condenser.—Condensation by injection, such as has been described already, is the system that has been almost universally adopted since Newcomen applied it in his engine. We have already alluded to another mode of condensation, by means of cold surfaces, which now begins to be adopted, and which, from the great advantages attending its use, will probably soon entirely supersede the *injection* method. On considering the mode in which a jet of cold water admitted into a vessel containing steam acts upon it, we readily see that the water, entering with considerable force through an aperture (usually fitted with a rose), presents to the steam a very great and minutely subdivided surface. Thus every minute particle of the water is at once surrounded by an atmosphere of steam, from which it abstracts so much heat, that the steam is almost immediately reduced to its liquid condition as soon as it comes in contact with the water: as a mode of condensing, then, rapidly and effectually, probably no better arrangement could be desired. But, after condensation, the injection-water, which, as we have seen, amounts to 15 or 20 times the quantity of water produced from the steam, forms the principal part of the water fed from the hot well to the boiler. If, therefore, the injection-water be impure, as it generally is ; and still more, if it be salt, as it always is at sea, the boiler is fed with the impure water, and is thus subjected to all the evils of deposit and incrustation, to which we have before alluded. The quantity of water actually required for feeding the boiler, is precisely the quantity derived from the condensation of the steam, with a small allowance for unavoidable losses by leakages. If, then, the steam could be rapidly and effectually condensed without mixing it with impure water, it would itself supply almost enough water for feed, and that of the purest possible quality, because it would be distilled. There appears to be no mode of obtaining the rapidity of condensation required for the efficient working of an engine, except that of exposing the steam to a very extended cold surface, just as it is exposed to the minutely subdivided surface of the water of injection, but without mingling with it. The condensers, called *surface-condensers,* are therefore constructed generally like tubular boilers. A box or casing, like the body of a boiler, has a great number of very small tubes passing from end to end, and tightly jointed, so that no communication can take place between the interiors of the tubes and the space through which they pass. In some condensers, cold water is made to flow through the tubes, while the steam from the cylinder is admitted into the box, and plays round the outside of the tubes in the spaces surrounding them. In other condensers the steam is made to pass through the tubes, which are surrounded by cold water supplied to the box in which they are contained. There are numerous modifications of form and arrangement of parts, and varieties in the modes of constructing the casing and of jointing the tubes to it, of causing the water to circulate, and in other details. But in all surface-condensers the general principle is the same—namely, that of exposing a very large cold surface to the steam, and of subdividing the steam so that every minute portion of its bulk is brought rapidly into contact with the cooling surface. In the best condensers of this kind now in use, a vacuum is obtained quite as good as was formerly obtained by the injection method; and, although an increased quantity of cold water may be demanded for keeping the surface cold, yet this is readily attainable at sea, and in most situations where condensing engines are employed. The very leakages are provided against by supplying for the loss of feed from this cause, distilled water procured from a small supplementary boiler, and all the evils of deposit, incrustation and priming over of viscid water, are effectually remedied. As water, before attaining its boiling point, parts with the air which it may have held in solution, the condensed steam contains no air, and thus the vacuum in the surface-condenser is maintained by the use of a much smaller pump. With the ordinary condenser, worked by injection, the pump is properly called an *air-pump,* because a large portion of its capacity is at every stroke filled by the attenuated air given off from the steam and from the water of injection. But with the surface-condenser, the function of the pump is almost exclusively confined to the removal of condensed water, the quantity of air evolved from the distilled water in the condenser being so small as to be almost inappreciable. The size of the air-pump is thus considerably reduced when surface-condensation is adopted, and less of the engine power is consequently absorbed in working it.

In respect to combined or compound engines—that is, the use of high-pressure in two successive cylinders, and its subsequent condensation we need not describe further, as they have already incidentally been mentioned. An excellent specimen of them may be seen in one of the folio plates of this work, and employed for pumping water at Buffalo U. S. A. A description of them will be found at page 279 *ante.*

With these remarks we may now dismiss the description of the steam engine, which has been confined chiefly to show those parts essential to every form, and therefore its general principles of construction and mode of working.

CHAPTER IX.

IRON MANUFACTURES—CUTLERY, ETC., ETC.

THE extended description which has been given of iron, steel, and their most important products on the large scale in chapter III., and subsequent chapters, leaves but little space for describing products, which although of much smaller size are yet of great importance in daily life. At page 88 some of the preliminary processes of manufacturing steel for making cutlery, &c., have been described and illustrated, and at page 87 the distinction existing between *blister*, *shear*, and cast steel has been pointed out. The tempering of steel for the manufacture of razors, lancets, pen-knives, scissors, knives, tools, springs, &c., has been dealt with at page 101. Case-hardening has been described at page 102.

It will be evident therefore that to a large extent we have anticipated the description of small articles of iron and steel manufacture, and we shall therefore in the present chapter merely briefly allude to some of the most important of these manufactures, referring our readers to the index of this work for reference to certain apparent omissions that may occur in the present chapter.

Swords, Cutlery, &c.—We can hardly fail to observe, that the most important use of steel is, and always has been, for the fabrication of cutting instruments of some kind or other. Files and saws are both of them cutting instruments, in a certain sense; but those implements which present a smoothness of edge are more properly designated by this name. The swords, daggers, knives, lancets, razors, scissors, and such like—these are the instruments in which the use of steel renders important services.

There seems to be pretty good evidence, that in almost all rude countries, cutting tools were made of bone, of flint, or of stone, before iron or steel tools were known. And the reason for this is plain enough, since the fashioning of a rude kind of knife out of a bone or a stone is simply a mechanical operation, whereas the possession of a piece of iron depends on a previous process of smelting. Most of our early navigators, in their accounts of the new islands and countries which they discovered, speak of the use of such cutting tools as are here alluded to. The New Zealanders, for example, have been accustomed to make saws and various kinds of tools of bone (Fig. 307, and 308). At Pompeii has been found evidence of the use of swords and a kind of armour made of bone. Flint knives were often used among the ancient Egyptians (Fig. 309); and many other countries present specimens of a similar kind, our own among them.

With regard to the knives and other cutting instruments made and used by the nations of the East in past times, Dr. Kitto, observes:—"They (*i.e.*, swords, knives, and cutting instruments generally) were successively, and afterwards simultaneously, of flint, bone, copper, iron, and steel. Probably at first a single knife or dagger, worn in the girdle, was made to serve all general purposes. Indeed, at present in the East, almost every one wears a dagger in his girdle, from the noble to the shopkeeper and husbandman; and although ostensibly a military ornament, it is rarely drawn for any more formidable duty than that which usually devolves upon a knife—from the slaughter of a sheep to the cutting of a string, or the scraping of a shoe. Homer's heroes kill their sacrifices with knives or poniards, which they wear by the side of their swords. In process of time, however, knives became scarcely less diversified in form and adaptation to particular uses than those which the shop of an English cutler exhibits. In sacrifices alone, three or four different knives were used—one for killing the victim, shaped like a poniard; another sharp, but rounded at the top to the fourth of a circle, for flaying; and a third, stronger than these, and of a cleaver shape, for dissecting the carcase. There were also pruning-knives, carving-knives, and hunting-knives. Some had the hafts worked out of the same piece as the blade, and others had handles of horn, bone, or wood. The engraving (Fig. 310) represents an assortment of cutting and stabbing instruments, selected from various ancient Egyptian sculptures, and such as were probably known and used by the Jews; particularly as in such articles there is, in however different times and countries, much analogy in general appearance. The 'knives and lancets' used by the priests of Baal were doubtless such as they employed" in killing and preparing the animals offered to the false god.

The swords and daggers of early times, and of Oriental countries at the present day, show frequently a good deal of richness and beauty of appearance, thereby indicating, that whatever might be the state of the other manufacturing arts at the time, the possession of a good sword was deemed a matter of much importance; while the knives for domestic use were of a very different character.

There have been some curious features connected with the sword manufacture in early

times. The Damascus blades, and the Toledo blades, have each in their own particular sphere acquired great fame for their excellence: the keenness of the edge and the extensive and perfect elasticity having been carried in them to the utmost point. We have all read of Orientals wearing their swords twisted round their waists, or even coiled up in their turbans, so great was their elasticity; and swords have been made so keen as to cut a silk shawl in two, while resting lightly on the edge. Such, at least, have been the reported wonders; but the Easterns may probably in this as in some other matters, embellish their stories a little.

One circumstance, however, is undoubted; viz., the existence in the ancient Damascus sword-blades of a wavy figured design, called "damask," or "damascene," from the name of the city. It is supposed that this was produced by some peculiar mode of combining different pieces of steel in the manufacture, though nothing certain is known in the matter. Many years ago a French experimenter, M. Clouet, made some swords which bore a very near resemblance to those of Damascus in this respect. He proceeded as follows:—The blade was composed of a number of thin plates of different varieties of steel, united together in the direction of their length by forging and welding; the surfaces of this compound bar were then worked upon with a graving tool, so as to produce a variety of hollows, which were afterwards worked up and brought nearly to a level with the faces of the blade; by this means an imitation was produced of a peculiar kind of tresses or curled lines seen in the Damascus blades. A further imitation of a sort of fleckiness in those blades was produced by M. Clouet, by welding together a number of steel rods, twisting them at a red heat, forging and twisting them several times in succession, straightening the compound bar, slitting it through the middle, and welding the two outer sides together, so as to render visible the grain which had before been in the heart of the bar. M. Bréant, another experimenter, sought to imitate a peculiar appearance which the Damascus blades present by mixing up a good deal of carbon with the steel from which the sword-blades were made.

Independent of this little-understood peculiarity in the Damascus blades, there has been in many countries a process adopted of inlaying sword-blades, as a means of decoration; this, too, has obtained the name of "damasking." Sometimes figures are produced in relief by cutting the steel; at other times the surface is engraved; and at others small pieces of metal are inlaid like mosaic in the surface of the steel. In one form of inlaying, the surface of the steel is cut into rather deeply, and thick gold or silver wire is beaten in so as to fill up the channels. In another, the steel is heated, and then hatched over with a knife; the design is drawn on the hatching with a metal point, and fine gold wire is let into the hatches at the lines of the device. Benvenuto Cellini, in his autobiography, speaks of his great desire to learn this art; he describes the damasking of the Turkish scimitars, and proceeds to say:—"The Lombards make the most beautiful wreaths, representing ivy and vine leaves, and others of the same kind, with agreeable turnings, highly pleasing to the eye. The Romans and Tuscans have a much better notion in this respect; for they represent Acanthus leaves with all their festoons and flowers winding in a variety of forms; and among these leaves they insert birds and animals of several sorts with great ingenuity and elegance in the arrangement."

The city of Toledo, in Spain, has been long famous for the production of sword-blades—one of the few branches of manufacture brought to anything like perfection in that unhappy country. The author of "A Year in Spain" makes the following remarks concerning a royal sword-factory carried on at Toledo:—"Here are made all the swords, halberds, and lances required for the royal armies. The establishment is on an admirable footing; and the weapons now made in it are said to be nowise inferior to those famous *Toledanos* which, in more chivalrous times, were the indispensable weapons of every well-appointed cavalier. Toledo was not only celebrated in the time of the Moors, but even under the Romans, for the admirable temper of its swords, which is chiefly attributed to some favourable quality in the water of the Tagus used in tempering the steel. As a proof that this is the case, one of the workmen told me that in the earlier period of the French invasion the manufactory was removed to Seville, where the national junta then was; but the swords manufactured on the banks of the Guadalquivir were found to be very inferior to those which the workmen had made in Toledo." Fig. 311 represents a group of ancient swords and daggers.

Under the generic term "cutlery," a great variety of articles is embraced, but whatever form any of these varieties present, they are all pretty much of a similar character so far as the routine of their production is concerned. Heating, hammering or forging, grinding, tempering, whetting, polishing, &c.—all modified in various ways according to circumstances, are employed in the conversion of a piece of bar steel into a cutting instrument.

Let us begin with *swords*, to which we have just drawn attention in regard to their history. The steel for making swords is brought to the factories in the form of "sword-moulds;" that is, pieces fitted to make one sword each. One of these bars is heated to a certain temperature, and hammered into form by two men, one of whom does the hardest work, and the other superintends the operations. When the sword requires to have a concavity or hollow given to the surfaces, it is hammered between steel projections or knobs, called "bosses." When the general form is given to it, the sword is hardened and tempered, by processes similar to those we have before described. It is then straightened and adjusted, next ground upon a large grindstone, then tempered again, and afterwards polished.

The making of knives presents, on a smaller

scale, a nearly similar series of operations. The form and decoration of a knife, however, lead to many peculiarities. At Sheffield the principal cutlers possess exquisite specimens of this kind of cutlery. Sometimes a knife, not larger than the thumb nail, will have a dozen or twenty blades, all perfectly formed and exquisitely polished. Another specimen has two hundred and twenty blades, all of which are exquisitely etched on the steel with portraits,

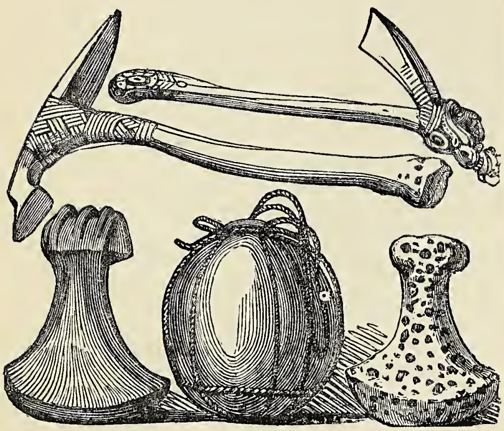


Fig. 307.—New Zealand Tools, made of Bone.

landscapes, and other subjects. A third consists of a knife having eighteen hundred and forty blades! all provided with hinges and springs, and all closing into one handle. Foreign countries occasionally furnish curious specimens of cutlery. Fig. 312, for example, gives a sketch of a "musical knife" deposited in the

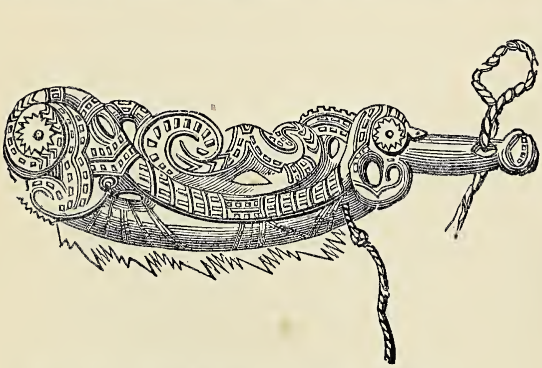


Fig. 308.—New Zealand Saw, made of Bone.

Louvre. Of this knife it is said:—"This very curious specimen of ancient musical taste is to be found among the miscellaneous collection of early French antiquities preserved in the Louvre. The blade of the knife is of steel, upon which is engraved the 'Blessing of the Table,' or Grace before Meat, which may be literally translated thus—'What we are about to take, may Trinity in Unity bless. Amen.' This is accompanied by the musical notes of the *bass* part only, so that there must have been a set of four or five knives, upon each of which the other parts necessary to make the composition complete were engraved. From the character of the musical notes, and the general appearance of the ornamental work that embellishes it, we should be inclined to fix the date of this knife

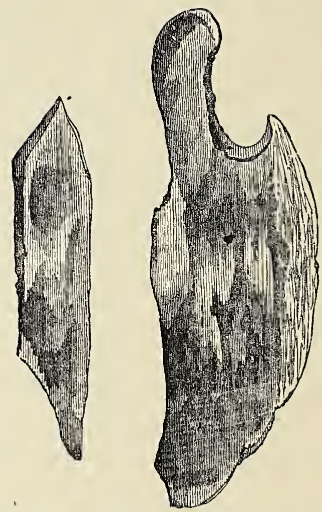


Fig. 309.—Ancient Egyptian Flint Knives.

somewhere about the latter half of the sixteenth century, when a taste for music was so universally felt, and its practical study so commonly exercised, that nearly every person with any

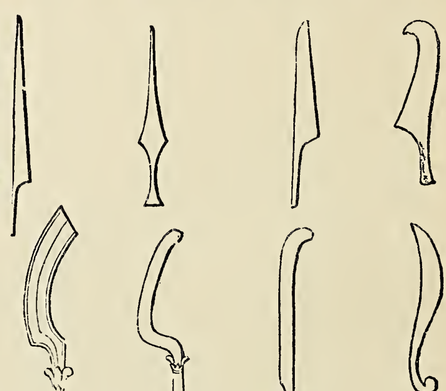


Fig. 310.—Ancient Egyptian Knives and Lances.

pretensions to respectability or a good education could play on some instrument, or at least bear a part in a madrigal or other composition. Not to be able to do so would imply the disgrace of

ignorance, or a culpable neglect of the necessary accomplishments of good society."

A table-knife, as made in modern factories, is forged out of a piece of bar-steel—"shear" steel for those of moderate quality, but "cast" steel for the best. A piece is cut off, long enough for one knife; and this is placed on the forge-fire until it has attained a red-heat. It is then taken out with a kind of tongs, placed upon the anvil, and there hammered till it assumes a form something like that of a knife-blade. The "tang," or that part which enters the handle, is made separately; or rather, the rudely formed blade is welded to the end of a small rod of iron, and the iron is forged so as to form the tang and also the shoulder between the tang and the blade. The whole is again heated, and hammered all over to complete the shape; the rusty-looking blade is then heated red-hot, next plunged into cold water to harden it, and then heated very gradually to a particular temperature, as a means of tempering it. Being

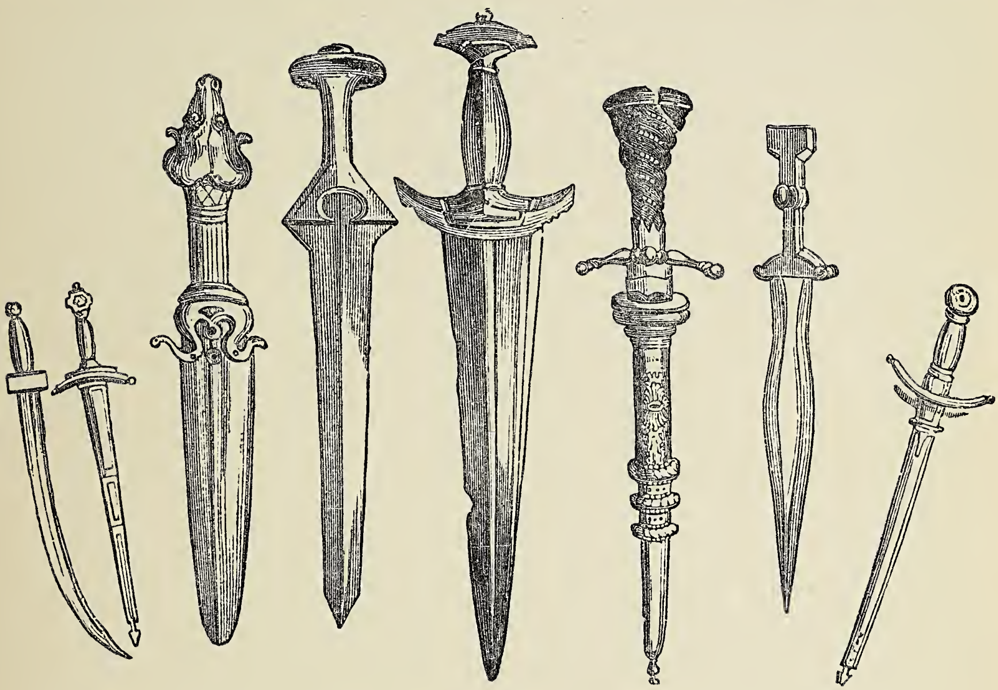


Fig. 311.—Ancient Swords and Daggers.

Fig. 312.—Musical Knife, in the Museum at the Louvre.

thus brought to something like the appearance of a knife, the blade is taken to the grinding-wheel, where it is ground in every part to give shape to the outline, regularity to the surface, and the first semblance of a sharp edge; the grindstone employed is three or four feet in diameter, and is formed of a roughish kind of stone; after the use of which the blade is ground on a smoother stone, called the "whitening-stone." After this "grinding" and "whitening," the blade is "glazed" or "polished"—a process, like the other two, effected by means of wheels, but of a very different kind. The "glazing" wheel is a circular piece of wood fixed upon an iron axis, and coated on the edge with leather; the leather is lightly touched, first with a solution of glue, and then with emery-powder, by the friction against which the blade of the knife becomes polished to a very high degree, and it is then fitted for insertion in its handle.

The making of *razors* differs from that of

table-knives, mainly in the greater degree of care required and bestowed. The bar of steel is not cut off to the length for a razor, but one end of the bar is placed in the fire to be heated, and it is then held by a man at the other end, so that the heated part may rest upon the anvil and the two men, the "striker" and the "forger," standing on the opposite sides of the anvil, speedily hammer the heated end of the steel into the form of a razor-blade, which is cut off from the rest of the bar, and carried through the subsequent processes nearly in the same way as the knife-blades, but with greater care.

One of the most particular points in razor-making is the determination of the proper heat to which to bring the metal in "tempering." If made too hard, the edge becomes too brittle for convenient use ; if not hard enough, the edge cannot be made fine and keen ; so that the point is to find a proper medium between two extremes. The cutlers generally determine this matter by the colour which the steel attains in the fire ; each kind of cutting instrument requiring its own particular colour or oxidation. This subject has already been fully dealt with at page 100 *ante*, and some remarks will there be found in respect to the change which steel may probably undergo during this process of tempering.

The making of *scissors* differs very little from that of knives. Each half may be looked upon as one blade, and is forged out of a narrow bar of steel. The anvil of the scissors-forger is provided with a number of little projections, hollows, and appendages, by the aid of which the proper shape is given to the various parts of the blade. To produce the hoop or handle, a hole is first punched through the steel, and this hole is gradually enlarged by the insertion of instruments into it while hot. In the cheapest kinds of scissors, each blade is cast in a mould, so as to save the trouble of forging; in large scissors, of better quality, the bulk of the instrument is made of iron, but the face of the blade consists of steel; in smaller scissors of the better kind, the whole substance is of steel. The grinding and polishing of the scissors-blades are effected as for knife-blades, and to these succeed the riveting of the two blades of each pair. At the present time a low quality of scissors is produced in great quantity, and sold at a low price, frequently to the loss and annoyance of the buyer.

Pen and pocket knives, or those which clasp into a handle, are smaller specimens of the same kind of work as that which produces table-knives; but the arrangements for adjusting them in their handles are far more minute and intricate than in other cases. So many are the little bits of iron, steel, brass, and other materials employed in making a clasp-knife of average character, that every knife passes through the workman's hands several times during the operation of putting all the various parts together : this is independent of the forging, and consists of a species of bench-work, in which small hammers, pincers, files, drills, gauges, polishing-wheels, burnishers, &c. are employed.

The making of the *handles* for cutlery, though not exactly a branch of manufactures in metal, is so closely connected with it as to form a large and important feature. The materials of which these handles are made are very various : pearl, ivory, ebony, bone, horn, hard wood—all are used for this purpose, under a great diversity of form. Each kind of material is the subject of a particular department of labour. In the working of ivory for handles, as an example, the elephant's tusks are cut up into pieces of a convenient size, by means of a small circular saw working very rapidly, and these pieces are afterwards shaped by other instruments, bored or drilled to form a receptacle for the tang of the knife or razor, and polished on the surface. Many kinds of hard wood are treated in a similar way. Pearl, or rather mother-o'-pearl, is, from its exceeding hardness, somewhat more difficult to work ; and as it is seldom used to form the substance of any article, it is cut up into thin veneers or slices, which are placed as an external ornament to some plainer and cheaper material. Horn, from its peculiar character, is worked up into handles in a very different way : when heated, it becomes soft enough to conform to the shape of a heated iron mould, by the aid of great pressure ; and it is by such means that the handles of numerous articles, such as umbrellas, &c., are made. Gutta-percha and ebonite are occasionally used for handles.

If we were to go through the range of the steel-manufacture, with its interminable variety of articles, we should find that forging, in some such way as has been here described, and casting in moulds made of fire sand, are the main processes whereby they are produced. Snuffers, fenders, fire-furniture, tools, chisels, instruments and implements of innumerable kinds—all are produced in some such way as above.

The art of wire-drawing and the manufacture of pins have been already described at page 138, *ante*. The making of nails and screws does not present any features of special interest. Needle-making is an important branch of the iron and steel industry, to which we shall presently briefly allude, noticing first the most important tools—the file and saw.

Although a *file* may appear a very humble mechanical tool, yet it is one of the highest importance in manufactures. As a means of abrading or wearing down the surface of a piece of metal, to give it any desired form or an additional degree of smoothness, nothing else is at once so effectual and so portable as a file, the little serrations on its surface wear down the metal to which they are applied ; and great skill is required in making these serrations or teeth with the necessary strength.

In this, as in almost all other varieties of the steel manufacture, the metal is *forged* in one part of the operations ; by which is meant a heating in a forge-fire or on a hearth, and a hammering by means of heavy hammers on an anvil. For making files, bars of steel of the proper width and thickness are selected, and cut into file-lengths. Each of these is placed among the burning fuel of a forge-fire, and brought to

a red heat. If the file be of large size, there are two men employed in making it, the "striker" and the "forger," who place themselves on the opposite sides of the anvil; both are provided with hammers and a number of small tools and implements, by which the red-hot piece of steel, held by pincers at one end, is quickly brought into the shape of a file, whether round, angular, or flat. When forged, the files or file-blanks require to be annealed, for the removal of the brittleness which they have acquired by the forging; this is effected, as in other examples of annealing, by heating the pieces of metal in a kiln or oven, and then allowing them to cool very gradually. After this, the surfaces of the pieces are ground on a large grindstone, by which they are brought level and tolerably smooth.

Up to this point the article produced is nothing more than a plain blank piece of steel; but it is now in a condition to receive the teeth or indentations which will convert it into a file. This is a very remarkable process, since it is one which has hitherto baffled all attempts to bring machinery to bear upon it. File-cutting machines have been invented from time to time, and brought partially into operation; yet in spite of the ingenuity shewn in their construction, they have failed in realising all the qualities required of them. Files are, therefore, still cut by hand, as they have been for ages. In this process the cutters sit in a row in front of a long bench with their faces towards a range of windows. The steel-blank is strapped down to a block or support, where the workman can conveniently act upon it. He holds in his left hand a very tough and sharp piece of steel, the edge of which is fitted to cut the teeth of the file; while in his other hand he holds a hammer. He applies the cutting edge to the blank, and by one blow of the hammer cuts one of the teeth; the edge is then removed to a distance equal to the intended space between two of the teeth, and another blow is given; and so on from one end of the file to the other. It is quite surprising to see the accuracy with which these several cuts are made; the strict parallelism which exists among them, the equability of depth and of width, the exactness in the slope or sides of each cut—all these are points which require years of practice to attain; and if a file-cutter quits the employment for any considerable time together, his fingers are said to lose a certain delicacy of touch which is essential to the operation. Some files have teeth only in one direction, while some have two series, crossing each other at a given angle; some are flat on both surfaces, others round on both surfaces, and others again flat on one side and round on the other; some have teeth formed of fine lines, while others have deep notches or hollows; some have only eight or ten teeth to an inch, while others have upwards of twenty; but whatever may be these diversities, all are alike produced by the file-cutter, who cuts one tooth at one time, let the whole number of teeth in the file be what it may.

As the file-blank had been rendered soft before the cutting, it has now to be hardened again. It is heated in a forge or kiln, and when brought to a certain temperature, it is plunged into a tank containing cold water, in which ale-grounds, salt, and other ingredients have been introduced: this gives a peculiar "temper" to the files, and enables them to bear the severe usage to which they are afterwards exposed. The files are then scrubbed clean with sand and water, and finally tested as to their soundness, by the clearness of the "ring" or vibration which they give when struck.

Another kind of mechanical tool, requiring quite as much care in its manufacture as files, is the *saw*; and this, like the former, is among the occupations which give life and activity to the town of Sheffield. Saws are made of three different kinds of material,—sheet-iron, shear-steel, and cast-steel; but all those of the better quality are of the last mentioned kind, and will serve to exemplify the others.

Ingots of cast-steel are first rolled or milled into sheets having the proper thickness for saws; and these sheets are cut up into strips by a suitable machine. The cut edges are made smooth by applying them to a grindstone, and one of the edges is then provided with the teeth which give it the character of a saw. This is effected by a kind of punching. There is a small press, having a triangular punch at its lower extremity; a man holds the saw beneath it and by the action of his right hand brings down the punch forcibly upon the surface of the steel, cutting out a little piece equal to the intended size of the teeth. He then shifts the saw a little, and makes a second tooth in a similar way; proceeding thus from end to end of the saw with great quickness. The size and form of the punch employed depend on the kind of tooth to be made, and vary greatly in different instances.

After the teeth are cut, the saws are "hardened," by being heated in a kiln or oven, and suddenly cooled by being plunged into a tank of oil. They are then slightly heated again, and while yet warm they are hammered at various parts, to remove any crookedness which the previous process may have given them. Next they are "planished," that is, they are rested on a polished steel anvil, and hammered repeatedly over every part, by which the substance of the steel is made uniformly dense, even, and regular. Then ensues the "grinding." This consists in attaching the saw to a flat board, and applying it to the edge of a grindstone, so as to grind off all asperities, and make the saw perfectly flat: the manner in which this is done is somewhat remarkable, since the workman seems to a bystander in imminent danger of being precipitated over the wheel, or of falling upon it while in rapid revolution.

Another hammering is required to remove the twisting occasioned by the grinding; another beating is given to restore the "temper;" and another (but very slight) grinding is given to remove the hammer marks. After which the "set" is given to the teeth; that is, the lateral

bending which every tooth of a saw presents. Here a curious example is afforded of the accuracy of hand and eye which long practice can give. The workman rests the saw flat on a smooth steel anvil, and by means of a very small hammer held in his right hand, he gives a blow to every alternate tooth, thereby bending it out of the straight line. He then turns the saw over, and strikes all the other teeth, so that every alternate tooth may be bent in a different direction. Although he runs along the saw with his hammer, giving blows as fast as his hand can move, yet he rarely if ever hits two adjoining teeth in succession, but always misses as many as he hits.

The needle, although perhaps the smallest of all iron manufactures, ranks really among the most important. Needles are made of fine steel-wire, brought to that state by the wire-drawers. It is brought to the needle-factories in coils or hoops weighing about twelve or fourteen pounds each, the length of wire in each coil depending on the thickness. The needles commonly made vary from $\frac{1}{22}$ of an inch in thickness, designated No. 1, to $\frac{1}{100}$ of an inch, designated No. 12; for a medium between these two, say No. 6, the coil of wire is about two feet diameter, it weighs thirteen pounds, and the wire contained in it (about a mile and a quarter in length) will make about forty thousand needles.

The coils of wire are unwound, and by means of a stout pair of shears are cut up into a number of separate pieces, each about three inches long. As all these pieces have conformed to the general bend of the coil, they are curved or crooked; and this crookedness is forthwith removed in a very remarkable way. The little pieces of wire are grouped into bundles, which are placed within two iron rings or hoops placed a small distance apart; they are heated in an oven, and when brought to a particular temperature, they are taken out, and placed with the edges of the iron rings on a flat iron plate. A man then takes a pronged instrument, which he rests on the needles, and rolls the rings backwards and forwards; by which action all the pieces of wire are made to roll repeatedly one over another, so that they mutually correct each other, and all are brought to a straight form. The pieces are of a length to make two needles each; and each one, in the next stage of the operation, is sharpened at both ends, to give the first semblance of points for the two needles. This pointing is a sad occupation, as the particles of steel get into the lungs of the workmen despite all the inventions that have been brought out to prevent this evil result. The needle-pointer sits behind a small grindstone which is revolving very rapidly, and applies the needles to the surface of the stone. The workman takes fifty or a hundred wires into his hand at once, and applies them to the edge of the stone in such a peculiar manner, that he makes every wire separately rotate on its axis, and grinds away the ends of the whole hundred at once: it is one of the most surprising manipulations presented in the arts, for he will give true and symmetrical points to ten thousand needles in an hour! The room is generally rather dark, but a vivid stream of sparks shoots off from the stone. The grinder wraps a handkerchief over his mouth, to prevent as far as he can the inhalation of the steel-dust; but they are a reckless class of men, who have refused to adopt many precautions which the humanity of others has pointed out to them; and they continue to be, what they have ever been, a short-lived race, seldom surviving the age of thirty-five or forty.

In the next stage of progress, two holes are made near each other in the middle of the wire, to form the eyes of the two needles. There is a stamping-machine consisting of a heavy hammer, at the lower surface of which is a die to give one half of the stamp or impress to the wire; while beneath is a block containing a die to give the other half of the same. The workman holds several wires between his fingers at once; drops one at a time on the lower die, and lets the hammer with the other die fall heavily upon it, which he is enabled to do by a string acted upon by his foot. The dies do not pierce two holes completely through the wire, but cut sufficiently deep to mark the size and form of the holes; and at the same time they form the channel or gutter which every needle exhibits near the eye. A boy next takes up a number of these partly pierced wires, spreads them out like a fan, and brings them one by one down upon a smooth steel surface, where two hardened and polished steel piercers descend, and drill the holes completely through.

The wires are then "spitted;" that is, they are taken up by children, and threaded or spitted upon two smaller wires, which are made to pass through both the eyes of every larger one. The stamping has occasioned a "bur" or protuberance near the eyes of each wire, and this bur is next filed down by a workman. These successive changes and processes may perhaps be better appreciated by a glance at Fig. 313; where the left-hand specimen is the wire for two needles, as uncoiled from the hoop; and the others represent it, in succession, when straightened, when pointed at both ends, when stamped, when the eyes have been pierced through, and when the bur has been filed off. The form of the eyes and channels is better shown in the three magnified representations.

The wire still continues double; that is, it is long enough to form two needles; but by a dexterous bending of the "comb" of wires, each one is broken into two, the separation being effected between the two eyes of each wire. The "stamping," "piercing," "filing," "spitting" and "breaking," have had the effect of bending the wires in some degree; and to restore the proper degree of straightness is the object of the process of "soft-straightening." This process is undertaken by females, each of whom sits at a bench, spreads out the needles on a flat iron plate, and rubs them very quickly with a bar whose lower surface is convex. Although the needles are rubbed one by one, yet the process is so conducted that three thousand are straightened by one person in an hour.

The needles are next placed on flat iron trays, and deposited in an oven, where they are brought to a certain temperature; they are then quenched in oil or cold water; and tempered by being slowly heated to a very exactly determined temperature. After this, every needle which may have been slighty bent by the heating is straightened while cold by a few blows from a very small hammer; and the whole are then ready for the process of "scouring." This is one of the very few departments of the needle manufacture in which machinery is employed. The needles are laid out parallel on a piece of canvas, to the number of twenty or thirty thousand; they are coated slightly with emery and oil, and wrapped up in the canvas to the form of a roll ten feet long by about two inches in diameter. Two such rolls are placed on a long slab or stone, and an upper slab is made to roll over them to and fro, very much in the same way as

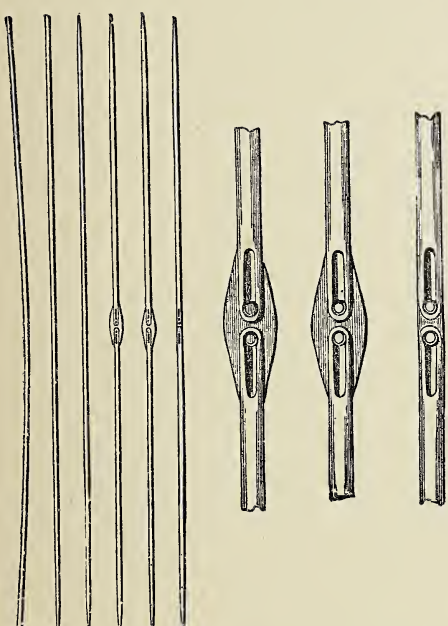


Fig. 313.—Succeeding stages of a Needle.

a mangle. For six or eight hours together this rolling is continued, by which all the needles are made to rub against and rotate amongst each other, mutually polishing their surfaces by the aid of the emery and oil mixed up among them. The canvas parcels are then taken out and opened, the needles removed and washed in suds, replaced in new pieces of canvas, retouched with emery and oil, and re-scoured. For the finest and best needles this process of scouring is deemed of so much importance, that the whole mass undergoes five or six different scourings of eight hours' duration each.

After the scouring the needles go through a number of minor processes. They are shaken in a tray, to bring them all into parallel arrangement. They are spread out on a table before a number of children, who with great dexterity separate them into two parcels, one having the heads towards the right, and the others towards the left. They are examined one by one, for the removal of such as may have been broken or injured in the scouring; a number which is said to amount to as many as sixteen or twenty in a hundred. They are applied to a very fine drilling-machine, by which the eye has a smooth-

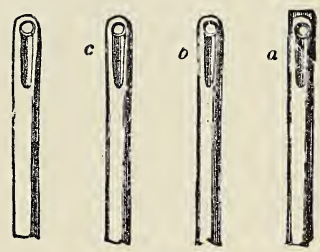


Fig. 314.—Needle-eyes in different stages.

ness and roundness imparted to its edges, as a means of preventing it from cutting the thread. They are "ground" at and about the heads by being applied to the edges of small grit-stone wheels in rapid revolution; after which they are similarly applied to the edges of "polishing" wheels, which are made of wood covered with leather, to the surface of which a little polishing paste is applied. So far as these minute shades of difference can be shown in a woodcut, they may be illustrated in Fig. 314; where *a* represents a needle with the eye and head rough; *b*, the head filed and brought to the proper form; *c*, the eye when "countersunk" and prepared for the last stage; *d*, the eye drilled and finished.

Such, then, are the numerous stages through which these tiny implements of steel pass, in their progress towards a manufactured state; and there are few other departments of productive art which show more strikingly the commercial importance to which even the most trifling articles arise when the demand and consumption of them are large. Sewing machines have demanded a new form of needle, but these are made in a similar manner to that already described.

Nails.—These, like needles, are among the smallest of iron manufactures, but at the same time are one of the necessaries of modern civilisation.

In making *nails*, the iron is sometimes brought to the state of thick wire as a preparative step; but more usually this is not requisite. A distinction between "wrought" and "cut" nails gives rise to many peculiarities in the manufacture; since the former are made from small rods, and the latter from sheets: the former are made by hand, and the latter by machinery; the former are made in small cottages or workshops,

and the latter in large factories, where steam-engines supply the moving power. It may be well to speak of the former of these two kinds first.

Whoever has occasion to pass along the public roads between Birmingham and the adjacent towns of Dudley, Walsall, Wolverhampton, &c., will be pretty sure to see indications of wrought-nail making. Here and there an open door will afford a glance into a rude kind of smithy or shop, where three or four persons are hammering away, and where a smithy fire affords the means of heating the iron. Along the road, too, may be seen persons carrying bundles of iron rods, which they have purchased of the iron merchants, and are about to convert into nails at their own dwellings. The rods are made of iron which has been rolled in sheets of the requisite thickness, and then cut up by slitting rollers into pieces having the requisite width for nails. The working up of these rods into nails is an operation in which all the members of a family frequently assist. In the first place, one end of a rod is placed in the forge-fire, and heated by the aid of two or three blasts from small bellows. The "nailor" takes it out of the fire and rests it on his anvil, which is a small cube of steel imbedded in a mass of iron. With a few dexterous blows from his hammer he quickly fashions the end of the rod into the required shape for a nail; and then cuts off the portion thus prepared. Another heating and another hammering produce a second nail; and so he goes on until the whole length of the rod is exhausted. By certain simple tools which he employs, the nailor is enabled to give any desired shape to the nail, and to fashion one end of it into the form of a head. The celerity with which all this is effected almost surpasses belief. There was one occasion on which a nailor undertook to make 17,000 large nails in a week, for two weeks together; a feat which he successfully accomplished. A provincial journalist afterwards made the following calculations as to the muscular activity involved in the operation:—"Those who do not understand the nature of the work may form some idea of the undertaking when they are informed, that the above quantity is allowed to be as much as three ordinary men can perform without difficulty; and that, allowing twenty-five strokes of the hammer (which is two pounds weight) to each nail, including the cutting of the rods into a size convenient to be handled, and re-uniting them when too short, there were no less than 1,033,656 strokes required before the task could be completed. In addition to this, the workman had to give from one to three blasts with his bellows for every nail he made, had to supply the fire with fuel, and had to move from the fireplace to the place where the nails were made, and *vice versâ*, upwards of 42,830 times!" This is, indeed, an astonishing specimen of handiwork.

The kind called "cut" nails have less toughness and strength than wrought nails. The general system is to cut up sheets of iron into strips whose width equals the intended length of the nails, and then to cut up these strips into small pieces shaped properly for nails. For the first of these processes the sheet-iron is held by a man up against a large cutting machine acting like shears, one cut of which severs a strip from end to end; and by shifting the sheet of metal an inch or two at a time, the whole of it becomes by degrees cut up in a similar manner. Each strip is then taken up in turn, and held against another machine, which cuts it up into nails. Cut nails are generally pretty flat, and do not project much at the head; so that, by making oblique cuts, slanting alternately in opposite directions, a number of wedge-shaped nails are produced, without any waste of material. In some of the machines there is a vibratory motion so as to give this alternation of direction; while in others the strip of iron is turned over after each cut. In either case the strip is held by a boy or man, and its end pressed up against and between the blades of the putting-engine. In some forms of the machine the iron undergoes a pressure as well as a cutting, by which an approach is made towards the strength and toughness of wrought nails.

We have endeavoured in the preceding and present chapters to describe the immense amount of riches which the earth affords us from *beneath its surface*, in the shape of coals, metals, &c., and which human ingenuity has adapted to an almost infinite variety of objects to minister to our wants and luxuries. In the following chapters attention will be directed to the riches that may be obtained from the *surface of the earth*, by means of agriculture and allied arts, and we shall see that it will be exceedingly difficult to find to which man is most indebted. It is a remarkable fact, however, that, as a rule, a country or district abounding in minerals is rarely fitted for agricultural processes, and *vice versâ*, a rich soil on the surface is but rarely accompanied by an analogous richness of mineral products beneath it.

CHAPTER X.

AGRICULTURE AND APPLIED SUBJECTS.

WHATEVER opinion may be held in respect to the date of origin of any other branches of human industry, no one can dispute that agriculture must take the first place in the history of them all. From the day that the first curse was pronounced on man, up to the last he will occupy this earth as a tenant, the labour of the plough and spade, of sowing and reaping, will last.

It would be invaluable to modern science and practice if we could trace the gradations through which the art has progressed. Ancient history, sacred and profane, but dimly acquaint us with what our earliest forefathers grew. That there was "corn in Egypt," although only a matter of historical interest, as connected with the early days of the Israelites, to some readers, is highly suggestive to the man of science and the practical agriculturist. We may naturally inquire why that country at the moment abounded in the means of food; for, admitting the storage of immense quantities of corn by the foresight of Joseph, how can we explain the possibility of such a provision for the years of famine, except on the ground that agriculture had made great progress as an art, although a scientific knowledge of its conditions might not be possessed by the Egyptians of those days? Another and strong confirmation of this opinion, may be gained by pointing out, that the grains of wheat found in the envelope of mummies, still retaining vitality after a lapse of 3,000 years or more, are amongst the most prolific species of our cereal crops.

It was not simply in the production of corn that the ancients excelled; horticulture was equally followed by them with the same success; hence we read of the longings for the cucumbers, and other garden products of Egypt, by the Israelites on their journey through the wilderness. It would seem that, from all accounts of ancient gardening, the gourd tribe was especially cultivated—such as the cucumber, melon, gourd, &c.; and this can be no matter of surprise when the heat of the climate in which the early inhabitants of this world lived is borne in mind. Such fruits are amongst the most refreshing in countries like Egypt, Arabia, Palestine, &c.; and to the present day are characteristic productions. The onion tribe was likewise largely cultivated, as numerous allusions in the Scriptures and secular early historians indicate.

Another evidence that the tilling of the soil had made rapid progress, is seen in statements that are made in respect to the use of manure. Thus, in the 2nd of Kings, a price of five pieces of silver was asked for the fourth part of a cab of dove's dung—undoubtedly the guano of those days. Referring on this point to China, we find in that country accounts of agricultural processes of ancient date, confirming the general knowledge of those principles and modes of practice that are now admitted by science to be the best for the production of prolific crops; and, without doubt, the abundance of leeks, onions, cucumbers, melons, &c., was then procured by the liberal use of the richest manure, just as is necessary in our day, in all countries, to produce the same result.

Coming down to a much later date—that of the Greeks and Romans—we find evidence of high culture, and much practical, indeed scientific, knowledge. The fact that Pythagoras forbade the use of broad beans to his followers, because they were "first cousins to man," is in exact accordance with the discoveries of modern science, which point them out as the most nitrogenised, or flesh-forming substances of vegetable growth. It is familiarly known to all, that nothing is "so filling" (to use a common, but expressive phrase) as broad beans; and this is because they contain so much nitrogen in their legumin. Pythagoras would, therefore, have more properly called them as "first cousins to flesh."

The Romans were especially noted for their advance in agriculture and horticulture. Pliny gives us many interesting details on the subject; and no one who has perused the *Bucolics* and *Georgics* of Virgil, will fail to perceive how high a rank, and perfect a practice, must have existed in respect to all pursuits of a farming character in those days. The Romans cultivated all the esculent plants, herbs, and fruits now esteemed in Europe, including cabbages, turnips, carrots, peas and beans, pot-herbs of numerous kinds, cucumbers, melons, &c., mustard, mushrooms, salads, apples, pears, walnuts, and other nuts, with a long list that cannot here be detailed.

At what period any branch of systematic farming was commenced in this country seems very uncertain. In the early history of Britain, its surface was abundantly covered with forest trees, and far more land was under water than at the present. The Thames, at that period, extended its bed over all the marshes of Essex, from near the Nore to far beyond London and the Kentish banks; while those of Surrey were similarly overrun with water far inland. And it was not till embankments were raised, subsequent to the Roman invasion, that the rich land now so productive of corn, and every variety of vegetable food, was made capable of culture. The absence of such a bank, and its probable consequences, were aptly illustrated a few years ago, when the fearful gunpowder explosion at

Erith occurred; for had not the gap occasioned in the bank been filled up, the results, for miles around, and even to some of the southern suburbs of the metropolis itself, might have been most disastrous.

There is no doubt that the greatest benefit that happened at that period to our country was its invasion by the Romans. The latter found barbarians as its inhabitants, only to be compared with such as, in modern days, were discovered in Feejee, and the islands generally of the South Pacific Ocean; and what we have done for these, the Romans, in part, did for our ancestors. But it was chiefly to the religious emissaries of Rome that was due this introduction of systematic agriculture and gardening. Settling, as they did generally, on alluvial soil, and near the banks of some river or stream, they availed themselves of the natural fertility of such grounds; introduced long-established and generally successful methods; and so taught, by easy steps, our rude and roving forefathers the art of culture. Iona (supposed to be the earliest settled locality of Christianity in this country; known also as Icolmkill, and one of the western islands of Scotland) has afforded us traces of the ancient gardens. Dr. Walker remarks—"On a plain adjoining the gardens of the abbey, and surrounded by small hills, there are vestiges of a large piece of artificial (ornamental) water, which consisted of several acres, and been contrived both for utility and pleasure. Its banks have been formed by art into walks; and though now a bog, you may perceive the remains of a broad green terrace passing through the middle of it, which has been raised considerably above the water. At the place where it has been dammed up, and where there are the marks of a sluice, the ruins of a mill are still to be seen, which served the inhabitants of the abbey for grinding their corn. Pleasure-grounds of this kind, and a method of dressing corn, still practised in these remote islands, must, no doubt, have been considered, in early times, as matters of high refinement."

But agriculture and gardening, once established in this country, could not fail to make rapid progress; for the soil being largely alluvial, and, of course, virgin, would quickly repay the labour of the husbandman. And here we may notice, that the peculiarity of the soil of a country decides the majority or characteristics of its vegetable productions, and, consequently, the kind of animals bred on it. Our islands, but especially England, are highly favourable for the growth of grass and corn generally; hence the great production of wheat, oats, barley, &c., and the extensive breeding and feeding of cattle; or the numerous pasturages of excellent grass that are generally spread through England, Scotland, and Ireland. On the continent, Holland and some adjacent districts have been long noted for the production of bulbous plants, vegetables, and flowers, which the Dutch produce in the highest perfection, and largely export to all parts of Europe. In the south of Europe, again, wheat gives way to rice and the vine; which, whilst we produce fruits of most other kinds, of the best sorts, will not ordinarily ripen with us. Fuller gives credit to the Dutch thus:—"Gardening was first brought into England for profit some seventy years ago (*ante* 1660); before which we fetched most of our cherries from Holland; apples from France; and hardly a mess of rath ripe peas but from Holland, which were dainties for ladies, they came so far, and cost so dear. Since then gardening hath crept out of Holland into Sandwich, Kent, and thence to Surrey; where, though they have given £6 an acre and upwards, they have their rent, live comfortable, and set many people to work."

The growth of agriculture and gardening, in this country, made great progress from the time of Henry VIII.; and in succeeding reigns, to those of the Charleses, much attention was paid to both. The discovery of the art of printing had then gained such perfection, that works were freely written and published on such subjects, diffusing information in respect to processes carried on here and abroad. The first complete treatise on gardening was published by the "herbalist," or gardener of Charles I.; and this example was rapidly followed by other works on that, and various branches of horticulture and husbandry.

The art of forcing was known amongst the Romans; but the introduction of hot-houses into England seems to date from the time of William and Mary; and in the time of Queen Anne, the present ornamental system of gardening was followed, in place of the old prim style till then adopted. The introduction of the potato had also extended the list of crops.

Making a long leap in the history of agriculture, &c., we find the first attempt at the application of chemical science was begun only at the commencement of the present century, when Davy delivered the first lecture on the subject. Commencing his lectures about the year 1802 on agriculture, he observes, in the introductory one—"Agricultural chemistry has not yet received a regular and systematic form. It has been pursued by competent experimenters for a short time only: the doctrines have not, as yet, been collected into any elementary treatises; and on an occasion when I am obliged to trust to my own arrangements, to my own limited knowledge, I cannot but feel very diffident as to the interest that may be excited, and doubtful of the success of the undertaking."

Here we have a statement, by the then first chemist in Europe, of the condition of agricultural chemistry in the first two or three years of the present century. Having read the lectures delivered by Davy at that period, we must admit, that, whilst his success was practically moderate, it was not on account of the imperfection with which he treated his subject. On the contrary, all the lectures indicate deep research, great accuracy of investigation and exposition for the time; and they certainly formed the basis of all that has since been done by the successors of that eminent man. When, however, we state that the basis of the present system of chemical science itself was only just

being laid; that all modern improvements have arisen from the subsequently formed system and practice of the science; and making all due allowance for the uncertain chemical analysis, knowledge of equivalents, &c., &c., of Davy's time, united with the prejudice that any encroachment of science was met with by the farmers;—we say, taking these and many other adverse circumstances into account, Davy deserved the highest praise for what he expounded.

Here we may make a few remarks on the existing prejudice, as having for years hindered the progress of agriculture itself, and of chemistry as connected with the art. Able and plain as were the lectures of Davy, the subject of agricultural chemistry died away, and was scarcely heard more of until Liebig took it up. Meanwhile, however, a few analyses of plants, soils, &c., were published; but they were of little value, and produced no effect. The premises, in most cases, were false; and the conclusions must, therefore, necessarily have been so. But, in certain cases, venturous individuals put forth pseudo-scientific views, that, being partially adopted, and failing, did far more harm than if the farmers had been left alone; for these persons, trying some of the indigested plans that were proposed, became disgusted at their failure, and threw chemistry, as the physic of the soil, to the dogs. It is not forty years ago since we heard a relation, one of the largest farmers in the north of England, remark, that science applied to agriculture was all "fash" (a north-country phrase for rubbish; or, *vulgice*, "humbug"). But the same individual, having his eyes subsequently opened, took good care to have his sons properly instructed in chemistry, as applied to agriculture.

But, besides the prejudice thus existing, there was not sufficient stimulus to persuade the farmer to exert himself by the introduction of improvements. The population of these islands was not much more, at the early part of this century, than half its present one. So long as there was a moderate harvest, there was abundance for the people. Had the farmer, again, increased his production, he would naturally expect his landlord to increase his rent, which increase would become permanent; whilst his prosperity would not only not be annual, but might not occur again for some years. Added to all this, the protective duties on corn were so great as to act as a bar to the introduction of foreign corn, and so tended greatly to increase the profits of the farmer. Consequently, in some bad seasons the price of corn became enormous. Indeed, we have heard a relation state, that he had given, towards the close of last century, as much as 2*s.* for the quartern loaf of bread. Taking these and many other allied considerations into account, it is no wonder that the British farmer adopted the Greek proverb of "hasten slowly"—if, in fact, he hastened at all. He was content with what his fathers had done, on the same farm, for years previously, and neither wished nor knew how to improve.

But agriculture does not only depend on the applications of chemistry for its advancement, but also almost as much on other sciences, and their applications. Geology, for example, which teaches the nature, disposition, and other conditions of strata and soils, has done much for the art. But thirty or forty years ago, the science was despised as a vision of dreaming enthusiasts and infidels; and as to its adoption as a guide in any branch of industry, that was considered as too ridiculous to be thought of, except by inmates of a lunatic asylum.

In a similar manner, vegetable physiology was equally despised as in any way applicable to agriculture. Entomology, although so much affecting the crops, so far as the destructive effects of insects are concerned, together with botany, had no place in the farmer's articles of belief.

A common, and by no means extinct error, also greatly hindered the progress of agriculture. It was usual to find that farmers had some pet theory, in the application of which, obtaining occasional and extraordinary success, they persuaded themselves into the idea of possessing an invaluable secret, that placed them in a much more advantageous position than their more ignorant neighbours. There was no intercommunication of ideas, facts, and theories, by papers read before societies, or published books; hence general ignorance in relation to some of the most important parts of their duties was prevalent; and, like all other kinds of ignorance, it was accompanied with an amazing amount of conceit. If, by some lucky hit, therefore, a farmer happened to obtain a better crop by his new method, manure, or other means, this was considered as a proof of his extraordinary luck or intelligence, of both of which he vaunted himself. Having full faith in this, he proceeded to apply the same means to every kind of crop or ground, and, of course, his method generally ended in failure.

The great benefits which science has rendered to agriculture, consist chiefly in showing what any special crop requires; and secondly, in pointing out what will supply the substance needed. Both of these requisites can only be suggested and taught by rigid and exact analysis, conducted under such conditions as can alone ensure success. It was the ignorance of these two facts, in former days, that made agriculture backward, uncertain, and, in fact, chance-work.

To illustrate this, we will suppose the following possible case. On one part of a field or estate, potatoes, turnips, and other similar crops, thrive well; but wheat, peas, and beans fail. Now, under the old system, or, more properly, method of farming, the only plan that could be adopted would be to try manures successively. Perhaps one year stable manure, in another lime, and so on, until the farmer had tried every available means in his power. Ignorant, however, of what each plant most required, he could not have the least hope of success with any degree of certainty; for how could he tell what the plant wanted? Thus the addition of lime to the soil growing the wheat, together with stable manure, would have supplied most of the essentials, probably for the wheat, peas, and beans: these require abundant earthy matter, such as lime, silica, phosphates, and so on. But, to a

certain extent, the application of these manures to the potato-field would have been only so much waste, for those crops do not require much earthy or nitrogenous matter; but, by the old plan, only luck or chance might hit the mark, but no certainty could be relied on.

By chemical analysis, however, the farmer, in a day or two at most—in fact, almost in as many hours—may decide, nearly to a certainty, what any part of the land requires. Analysing the soil, he finds it deficient in lime, silica, potass, phosphates, and so on; and he will find, from present teaching, that either artificial manures, also carefully analysed, or, still better, guano, will supply all that the land needs. Relying on the teachings of science, confirmed now by many years' past experience, he purchases the manure that his analysis indicates as requisite; applies it also according to sound experience; and, if heaven withhold not the rain, dew, and sunshine, his eyes are at last gladdened by a bountiful harvest; and whilst his barns are well filled, his intellect is brightened and further informed.

Science, therefore, teaches the farmer his wants, and, at the same time, instructs him how to supply them: it hence is an invaluable guide, leaving him in little uncertainty as to the course he should take. It does away with all empiricism, and so places agriculture, and its branches, in the position of a sound scientific occupation.

It is not, however, alone necessary that chemical analysis should direct as to the choice of manure, and also of the kind of crops that may be sown, in accordance therewith, on certain soils; for the practical farmer learns by experience that there are other conditions of success, equally as essential. Thus all the guano in the world spread on an Irish bog will not make it grow wheat. In other words, whilst a certain amount of moisture is absolutely requisite to cause the germination of the seed and growth of the plant, an excess of it will prevent both, and cause mildew or rot.

Hence has arisen the necessity of an extensive system of drainage, that has been so much adopted of late years; and by which hundreds of thousands of acres in this country have been reclaimed from moss, fern, and stiff cold soils, and rendered fertile, and, indeed, rich in harvest. But drainage, whilst it draws off the water to a certain extent, robs the soil of its richness, and therefore chemistry and drainage must go hand-in-hand. Some crops will grow in a moist soil: thus some of the finest grass grown in Scotland, is produced in the Craigintenny Meadows, between Leith and Portobello, near Edinburgh, where the sewage of that city is constantly allowed to percolate between the roots of the crops; and that has produced them in such an abundance on the edge of the sea, with a sandy subsoil, as to have become a proverb throughout the land. So great has been the success of this plan, as to have led to the formation of a company, with immense capital, thus to utilise the sewage of London, by conveying it to the Maplin Sands, which were intended to be reclaimed from the sea, off the coast of Essex. On the other hand, some crops cannot grow in water, or wet, stiff soils; and in such, chemistry, drainage, and mechanical action, are combinedly necessary. An instance of this is present before the room in which this is being penned. A thick, stiff, undrained clay has been turned up, exposed to atmospheric action, and abundantly manured with chalk; and the beans sown in it are now luxuriant in foliage, with strong stems, and exceedingly healthy appearance. On the same kind of ground, a few feet off, precisely the same kind of beans were sown at the same time; but the ground being left undrained, without lime, and merely turned up to sow the seed, has not produced the slightest sign of vegetation. This instance is an illustration of what may be seen all over the land.

Judicious application of scientific principles, but guided by an equally judicious appreciation of the circumstances, are absolutely requisite in dealing with every sort and every crop.

Another point of scientific and practical importance, and a feature of modern farming, is that of a different and efficient system of ploughing the land. We cannot here enter into all details connected with this question, which will be done hereafter. For the present, we shall be content to notice such general principles as will enable our readers to appreciate one more benefit that science, but especially chemistry, has conferred on agriculture.

Formerly it was a universal practice to let the land lay fallow for a year. After it had produced corn, turnips, &c., for some time in succession, the land was allowed to rest. Indeed, in the early books of the Scriptures this practice was enjoined. Until recently, however, the reason of this was not understood. It may be briefly explained as follows:—

All plants draw most of the carbon of their constitution from the air as soon as their leaves begin to appear above ground. Before that occurs the starch of the seed supplies sufficient. But the mineral constituents of plants are drawn from the soil; and it is there that what we may call the bony structure of the plant is formed. For example, the leaves of many species of grass are coated with minute crystals, sometimes sharp enough to cut the fingers if a blade be drawn between. Now these crystals are formed of silica—the pure form of flint, that has been drawn to, or assimilated by, the plant.

But this silica is one of the most insoluble substances in nature. In an ordinary state, it is only possible to dissolve it in the cold by the most powerful acid of the chemist—the hydrofluoric, that is rarely found in any ordinary farming soil. But nature provides with the silica its solvent, and that is some alkali, but especially potash. In the laboratory, it is usual to mix powdered flint or sand with two or three times its weight of carbonate of potash or soda, and expose it for an hour or two to the action of at least a red heat, when the silica becomes dissolved, and is then soluble in water.

In nature, in the cold soil, no such operation can be carried on; but still the solution is effected, and by very simple means. On ploughing up the ground, and leaving it to the action

of the air and moisture, the potash contained in it gradually dissolves the silica, and so renders this fit for the nutriment of the plant. Here we must notice, that neither the root nor the radicle of a plant can absorb or take up solid matter. Just as, in the animal, no solid matter, in that state, can enter or form the blood until it be converted into liquid, chyle, &c., so, in plants, the mineral constituents must first be rendered soluble, or they will be valueless.

Hence, in ploughing up the land, we expose its constituents to all the disintegrating force of air and moisture; and gradually the lime, silica, magnesia, iron, phosphorus, sulphur, &c., are rendered soluble, and so are in a fit condition for rendering to the plant proper and available nutrition. Few, unacquainted with the practical details of this subject, can believe the quantity of solid matter thus taken from the soil. As already mentioned, it is a point of the utmost importance that we should first ascertain what a plant wants, and whether the soil possesses such substances; but now we also may see that an allied question also arises; and that is, how much will a certain crop take from the soil? To illustrate the extent of this abstractive action, the following particulars may be adduced. At the same time we do not vouch for their accuracy, but they are near enough for our purpose at present.

2,500 pounds weight of wheat will take, in growing, of—

Potassium	48	pounds.
Sodium	5	,,
Calcium	19	,,
Magnesium	16	,,
Iron	3	,,
Phosphorus	32	,,
Sulphur	16	,,
Chlorine	2	,,
Silica	192	,,
	333	

Thus we see that wheat takes up about one-eighth of its weight of mineral substances in the seed per acre of ground.

But other crops vary in their proportions of robbing the soil. Thus, thirty tons of turnips, grown on an acre, will take up—

Potassium	300	pounds.
Sodium	58	,,
Calcium	170	,,
Magnesium	40	,,
Iron	10	,,
Phosphorus	80	,,
Sulphur	126	,,
Chlorine	10	,,
Silica	45	,,
	839	

Now, comparing the abstractive power of the two kinds of crops, we first notice the great relative difference that subsists between the proportions of each mineral substance; and, secondly, from the great amount of mineral matter taken away, we see the necessity of replacing it by manures, lest the soil should become so impoverished as to be incapable of further production.

Another result of chemical science applied to agriculture, and consequent upon what has been already explained, has been the great stimulus that has been given to the utilisation of waste substances, in the formation of various kinds of manures.

Into the different qualities of these, and the use of sewage, we shall not here enter, as all our present remarks are merely introductory to the fuller discussion of such subjects hereafter; but a general glance at them may be of value, in connection and continuation of what has been said already.

Formerly, stable and cow-house dung, lime, seaweed, fish of various kinds, soot, and a few other unmanufactured products, formed about the extent of the farmer's list of manures; and it was not until exact analysis of plants and soils had been effected, that any attempt was made to work up other articles into useful and effective manures.

When, however, it was discovered that nitrogen was essential to plants, various substances containing that element were utilised. Guano, as a natural product—at least we may so call it, as far as our means of obtaining it are concerned—presented, in one substance, almost all the wants of the farmer. Its intrinsic chemical value, however, soon raised the price; and, like many other substances, it soon began to be shamefully adulterated. The two causes of price and impurity led to attempts to imitate it; and now blood, waste pieces of all parts of animal bodies, urine, fæces, and other substances containing nitrogen, which were allowed to accumulate, putrefy, and breed pestilence, are united with lime and other matter by the manure-makers, and sold to the farmers in immense quantities as artificial manures.

Phosphoric acid was also, by chemical analysis, determined as essential to wheat and other crops affording food to animals, the bones of which are formed in the body by the gradual absorption of phosphate of lime from their food. This stimulated the production of some manure abounding in phosphates; and thence commenced the manufacture of bone-crushing. The production of superphosphate, by the addition of sulphuric acid to the bone, and other forms of bone-manure besides this, is now carried on to an astonishing extent. The successful use of the manure led to that, also, of a natural fossil, called *coprolites*, which have been formed from the fæces of extinct animals, and are found in large beds in some parts of this kingdom.

Ammonia, as before stated, containing much nitrogen, was in great request: formerly it was chiefly derived from soot, excepting, of course, dung manures; but now it is largely produced by the gas companies, or by those who purchase gas-liquor. This contains ammonia sufficient to produce one pound of the sulphate for every gallon of the liquor; and, at one time, the latter was considered of such little value as to

make some gas companies thankful if anybody would take it from them, almost as a gift. Indeed, some years ago, one of the London gas companies entered into a contract with a manufacturing chemist, for him to take all their ammoniacal liquor at the rate of 1*s.* 6*d.* per butt of 108 gallons. Now the sulphate manufactured from that quantity is sold at from 13*s.* to 15*s.*, and is not only a source of great profit to gas-makers, but a most advantageous manure to the farmer.

Numerous other instances of the utilisation of what had been previously wasted, might similarly be instanced, as having been turned to the benefit of the farmer. As they will receive attention hereafter, we shall omit mention of them, the examples already adduced being sufficient for our purpose.

Another great advantage that modern farming has reaped from science, has been the introduction of machines for doing almost every kind of out-door work, formerly effected by men, horses, or cattle. The two last are manageable animals, but not so man. Every farmer, necessarily, must keep a regular number of hands for the ordinary day-work of the farm ; but at ploughing, sowing, reaping, and threshing seasons, he requires a great increase in their number. And not only so, every farmer requires such an increase at the same period ; hence the demand for human labour often so far exceeds the supply, that soldiers in barracks adjacent to farms, have been frequently pressed into the service, especially at reaping-time. This great demand for labour, of course, induced the most capricious and extortionate demand in respect to its price. At certain seasons of the year, we have seen the steam-vessels plying between Irish and English coasts, literally crammed by natives of the Emerald Isle, coming over especially for the hay-making and reaping seasons—creatures that, apparently, had scarcely ever tasted animal food in their lives, and lived in hovels unfit for pigs. Yet, at the conclusion of the season, many of them will return home begging their way to the port on foot, although, perhaps, with £20 or £30 in their pockets.

Now all the inconveniences occasioned by the preceding causes have been either modified or removed by the invention of machines for nearly every operation of the farm—sowing, reaping, threshing, ploughing, &c. Portable steam-engines may be generally seen at work, at the present time, at most large farms—an innovation that would have horrified as well as terrified the former tillers of the soil. These machines do all the work less wastefully, and far better, than under the old method by man and animals. They require no food unless when at work ; and hence they are highly economical, especially to those who are situated at some distance from any labour market.

The last result to which we need here allude, in connection with what science has done for agriculture, is that of the improved means of transit for the products of the farm to market. Formerly, this was a slow and expensive operation, whether as regards the crops, animals, milk, &c. Now the railway system has become so extensively developed, that most of the large farms in England and Scotland are in connection with the leading markets by a comparatively inexpensive route ; and, in Ireland, the canal system supplies an equally available means. It is surprising how much a farm is benefited by such ready means of forwarding the produce to market. We have seen, before the completion of the northern system of railways, in Scotland, eggs sold at 1½*d.* to 2*d.* per dozen. At the present day, the great demand for them, and railway accommodation, has raised their price, and that of all other produce of the farms in those and similar districts, to a large extent. Milk is an especial instance of the kind ; and a visit to any of the termini of the London railways early in the morning, will best inform the reader of the enormous quantity of that article daily sent into the metropolis for miles around it.

The general effects of the application of science to agriculture, are, of course, too numerous to be here specified. Besides producing food in greater abundance, the improved system of farming has given great increase in the amount of employment, whilst the condition of the labourer has greatly improved. This has been attended with better housing and food, than when, previously, the men and women were huddled together like wild beasts, and treated like slaves of some feudal baron.

The extensive system of drainage that the chemical conditions of agriculture have induced, has had a marked effect on the climate, not only in localities, but generally throughout the country. It is always noticed, that where marshy districts, and cold, stiff, wet soils abound, there miasma is also prevalent ; whilst agues, rheumatism, and numerous forms of intermittent, with typhoid fever, afflict the whole of the inhabitants to a greater or less extent, according to the strength of their constitution.

In many parts of this country, where the draining has been effectually carried out, these diseases have almost disappeared ; and the more extensively it is adopted, the less water will be left on the surface of the land, and therefore, gradually, the dryness and temperature of our climate will increase.

We have thus endeavoured briefly to trace the gradual progress of agriculture, and some of its branches, from the early ages to the present time ; and, imperfect as our sketch has been, it will be sufficient to show how much has been done for it by science during the last sixty or eighty years. We have seen that, in 1802, Davy was the first publicly to expound those principles on which now all agricultural operations are invariably conducted. He, at that time, was the only instructor, in our islands, of the relations which chemistry holds to the tilling of the soil. Now, almost every district of the country has its agricultural or similar association, where all recent discoveries are canvassed, new processes are explained, and information generally is interchanged between the members. Books relating to subjects of science and farming are numerous; and colleges have been established,

where young men may not only get the rudiments and practice of science taught them, but also gain practical experience in all branches of farming, by studying them on farms attached to such colleges. The farmer is no longer a lump of humanity, capable only of growing crops or breeding; but he has become the intelligent man, able, in many instances, to enter into all the investigations of chemistry that are required to assist him in managing his farm; or, if not so advanced, he has at least the intelligence to avail himself of professional assistance, and to abide by its guidance for the direction of his conduct of the farm. The labourer is stimulated to steadiness, sobriety, and to gain a knowledge of his duties, in place of being treated as a two-legged animal, necessary for the farmer's use, and not further cared for. The ground, instead of growing thistles, is weeded; in place of being constantly wet, is well drained: the barren heath, and the sand on the sea-shore, with rocky surfaces formerly destitute of herbage, are all now rendered not only fruitful, but profitable. An increasing population has an increase of food provided for it, at lower prices, and in greater abundance, than was previously known; and thus, for years, famine has not stalked over any part of our country in which industry, perseverance, science, and capital have been applied.

With these remarks we conclude the introductory portion of our subject. In the future pages, the primary object will be, to show how chemistry is applicable to agriculture generally; but it is so intermixed with other sciences, that we shall frequently have to diverge, right and left, to embrace subjects but indirectly connected with it as a pure science, but essentially so in its applications. We shall have to inquire into the chemical constitution of plants, of soils, manures, &c.; the nature and qualities of nutritive matter abstracted by the growth of wheat, grass, and other crops; the mode of chemical analysis that is to be adopted; together with a vast variety of subjects connected with agricultural operations.

It is almost impossible, in the limits of this work, to do so extensive a subject justice. Indeed, in many instances, brief notice of some matters, with reference to works specially devoted to their consideration, will be necessary. The information of most value to our readers, will be that which will assist them in the active operations of the farm; and hence, whilst expounding the principles, we shall endeavour, at the same time, to be as practical as possible. It will be impossible for us to embrace in our descriptions those of all kinds of systems of farming that have been proposed or adopted. But as these are frequently of more local than general interest, no inconvenience will arise from the omission, more especially as the majority of the principles, doctrines, and facts we shall deal with, are of general rather than special application; that is, every farmer will require to follow them, whilst some must necessarily modify them to the special circumstances of his land, its constitution, elevation above the sea-level, and similar conditions affecting its power of fertility.

SCIENTIFIC PRINCIPLES OF AGRICULTURE.

Whatever art or industrial process is in any way connected with science, it generally occurs that not only one, but several, branches of philosophy are involved in its pursuit. Thus, in dyeing and bleaching, chemistry and botany are intimately commingled; in the production of artificial light chemistry, physics, and botany are similarly allied; and in the subject now before us, so extensive is its range, that nearly every branch of experimental science and natural history are connected with it, directly or indirectly. It would, therefore, be necessary, to do ample justice to the subject, that we should enter on a brief disquisition of many branches of science. But this would, whilst occupying much space, become exceedingly tedious and complicated in the details. A selection will, therefore, be made of the most prominent scientific details of agriculture, and minor points will be merged into them.

It will be evident that the following points are of the utmost importance:—

First, the *Geological* conditions, under which we shall notice the variety and derivation of soils.

Secondly, the *Chemical* conditions, that deal with the constitution of soils, and the products they afford for the nutriment of the plant.

Thirdly, the *Physical* conditions, such as texture, firmness, moisture, subsoil, drainage, climate, &c., &c.

And, lastly, the *Botanical* conditions: under which head fall the choice of the seed to be sown; its requirements under all the previously named conditions; the nature of its product; and other such considerations. We shall, therefore, deal separately with each of these subjects, as leading to practical results of the highest importance.

Geological Conditions.

Of course, confining attention to our own islands, their peculiar position and general constitution afford, as it were, a microcosm of the whole surface of the earth.

Taking the natural constitution of the surface, subsoil, and underlying rocks, we find every variety of strata and soils. Commencing at the south-eastern extremity, we have the rich calcareous or lime soil of Kent, so noted for its corn and fruit productions. Running from Dungeness and Dover to Whitby, chalk abundantly underlies or crops out of the surface; and along a large portion of this area some of the most productive parts of our country exist. It must be remembered, however, that calcareous, or chalk soil, perfectly pure, is barren; hence the white cliffs of Kent bear nothing on their face; although *on* them, when clay, &c., is mixed, they are highly productive. Generally, silicious and aluminous matter (flint and clay)

are also present, and, with a considerable amount of decomposed vegetable matters, such soils are usually highly fertile. The soils of a large part of Essex are of a similar character; and there, again, the wheat crops are not only abundant, but the produce fetches a high price in the market.

Generally, chalk rocks absorb much water, but do not readily part with it. But in nearly all our cretaceous rocks crevices are constantly occurring, that form a natural mode of drainage. For example, near the commencement of Margate pier, at the extreme east of Kent, a pump, the sides of which are surrounded with the sea at high-water, yields, to the astonishment of visitors, an abundant supply of fresh water, owing to a crevice in the chalk of adjoining rich wheat and bean land. So all round that coast we have noticed, during the last twenty or thirty years, constantly fresh-occurring crevices, by which natural drainage is carried on; hence the numerous streams that occur through Kent, and counties running north from it—from Dartford to Watford, Tring, &c.

One advantage of a chalk soil arises from the readiness of evaporation of moisture from its surface. It has hence become proverbial, that the ruin of England (in respect to excessive rain) is the blessing of chalky Kent. But, although evaporation is readily carried on at the surface, still a retentive power for moisture generally protects the farmer from drought, and the presence of clay assists to the same end.

Hard limestone, which is also a chalk rock (carbonate of lime), from its physical nature hard, is unfertile until broken up by air, moisture, or mechanical means. Then, like chalk, it becomes fertile; so much so, indeed, that we have seen oats growing on a limestone rock near Glasgow, the depth of the soil on which was so slight, that a carriage wheel passing over it would expose the solid limestone to view. The effect of frost, changes of temperature, the growth of small plants, &c., all tend gradually to render the solid chalk and limestone fertile, through breaking it up into powder; and so affording not only the food for the crops, but also the mechanical condition necessary for the spread of the radicles or little roots of the seed in search of food and moisture.

A large proportion of the wheat and grass lands of this country are composed of clay, and pass under the name of clay or aluminous soils. They are chiefly constituted of the matter of pure clay (*alumina*), united chemically with pure flint, or *silica;* the latter being an acid, and forming, with the alumina, what is chemically termed a *silicate of alumina.* The older clays of this country contain little chalk or calcareous matter, being mostly derived from the decomposition of granite and allied rocks. In the gault and lias, found in the middle districts of England, there is much calcareous matter, with little sand. But attention to the chemical constitution of the soil, by which, as already pointed out at p. 347, *ante,* we are enabled to find out the excess or deficiencies of soils, at once suggests a remedy. Thus, by adding lime to stiff retentive clay, with sand, gravel, manure generally, and burning a portion of the clay to mix with the soil, such lands become amongst the most productive of heavy corn crops and for pasturage, instances of which we have in the reclaimed fens of Cambridge, Lincoln, and Huntingdon shires, noted as much for the excellence of their corn crops as for their dairy produce. Bulbous or tuber crops rarely grow well on such lands—as the turnip, potato, carrot, &c. Undrained and uncultivated, they afford only coarse grass and useless weeds. Indeed, they are the outside of the garden until science and industry break down the barrier, and convert them into some of the most fertile of soils.

What is termed London clay extends over the chief parts of Middlesex, the south of Essex, and the south of Hampshire. It is highly retentive of moisture, tenacious, and adhesive hard to work, whether by the plough or spade. By throwing it up in masses, and allowing air and moisture to act upon it, with the addition of lime, &c., it will afford good crops of grass, and excellent beans and peas. Generally but little corn is grown upon it, except where the chalk is adjacent; and there, as in Essex, excellent wheat is grown not far from the banks of the Thames, inland and northwards.

Surrounding this is the plastic clay that is common in Hampshire, Dorsetshire, northern Essex, Norfolk, Suffolk, and some parts of Kent. It contains sand; and is rendered fertile for corn crops by bringing up to the surface the sublying chalk. Generally both of these clays are unproductive; but by good farming they may be rendered as amongst the best, most constant, and generally productive of any in our islands. The market gardens near London are the best proof of this statement; for there the stiff strong soil is made productive of every fruit and flower that can be grown in our islands.

In the interior of England, from Dorsetshire into Yorkshire, the great oolite bed or strata extends with varying width. The oolite, or roe-stone proper, is chiefly chalk (carbonate of lime); but in the long area we have named, various soils overlap and intermingle with the subjacent or natural strata, and of equally varying capabilities, as far as the farmer is concerned. Oxfordshire is especially oolitic in character; as are also portions of Cambridge, Huntingdon, Lincoln, Northampton shires, with parts of Norfolk, in the fens of each of which the oolite is the sublying strata. In all these good drainage is most essential; and by equally clever farming, in respect to ploughing and manuring, grass or pasturage, and corn, may be well reared. In respect to grazing, it will be familiarly known to most of our readers that the localities just named are amongst the best in England.

Sandy soils are numerous and varied in these islands. They are either composed of pure sand, which will grow nothing but coarse herbage, such as furze, &c.; or mixed with clay, when they become more productive. Sand, of

course, naturally drains itself, as is familiarly known on the sea-shore, where almost the instant the water quits its surface, the sand appears almost dry. Thus it becomes an important element in drainage; for, if mixed with stiff clay, it diminishes the retentive power of the latter, and thus increases its fertility. By the addition of clay, lime, and various manures, the sand, even of the sea-shore, may be made highly productive. An example of this has been given at p. 346, *ante*, in respect to the meadows watered by the sewage of Edinburgh, where the thickest and richest crops of grass are obtained literally from sea sand. We have also noticed some fine corn crops in Elginshire, and neighbouring counties of the Moray Vale, that were, apparently, growing out of pure sand which had been highly manured.

Sand, however, must not be confounded with the sandstone formations, so called by geologists. Sand proper has been placed in its present localities by purely mechanical causes, and these brought it from a distance where the sand first existed in the form of a rock. Doubtless the force of water was the cause; and numerous instances are met with throughout our country; a familiar example of which is found in the heaths near London, in many of the long valleys of England, and on numerous moors, &c., where it overlays rocks of entirely different constitution, from which it could not possibly have been derived.

The sandstone proper—that is, the strata, so termed geologically—is subjacent to, or crops up, in the land of some of our richest districts. Thus, the *new red sandstone* commences in Devonshire (where, also, the *old red sandstone* occurs, as in Cornwall and Scotland); and is found, also, in North Wales, Lancashire, Yorkshire, Cumberland, Cheshire, Worcestershire, &c.; and on both new and old red sandstone some of our most productive soils are found. At times, the presence of the oxide of iron is so great as to render a ploughed field, in some parts, of a deep-red colour. These soils were those earliest worked in this country; and for several centuries, farming, either for crops or pasturage, has been most extensively carried on in or over them.

The igneous rocks, such as granite and its allies, and the metamorphic, as slates, &c., are totally unproductive *per se*, being absolutely incapable of affording, in their solid condition, the least nutriment to plant or animal. Yet from them the best soils are gradually produced, by the disintegrating effect of air, moisture, and frost. Some remarkable instances of this may be met with in many parts of these islands, but especially in Scotland, northwards in Aberdeenshire, and in the south-west, between Dumfries and Wigton. On the route of railway between the extremities of the latter country, miles may be traversed where, owing to the occurrence of granite, nature seems absolutely dead, except where, at the bottom of the granite peaks, chemical action has decomposed the solid rock, and produced a little food for the scantily-spread grass and stunted herbage. Visiting such a scene, despite its wild grandeur, brings the contemplative mind almost back to the incipient end of chaos—a period when we might suppose that life was beginning to be. Uncouth form, the jagged, perpendicular, needle-like rock, perhaps half hidden at the top by cloud, an utter absence of sound or life, combine to render such a scene highly impressive, not to say saddening.

But from this we turn to the brightest localities of farming operations, which, from the earliest history of man, have been chosen as the favourite spots for commencing the tillage of the soil—we allude to the alluvial soils at the mouths and on the banks of rivers, usually so rich in every requirement of the art of agriculture.

The formation of these is easily accounted for. From the source to the mouth of a river the stream is constantly collecting and carrying animal, vegetable, and mineral matter, driven forward by the force of the current. At its narrow parts, where the stream has its greatest impetus or force, these matters are held in suspension and solution. But as the gorge or bed of the river widens, of course its speed or rate of travelling becomes gradually diminished, and therefore the coarse particles must be gradually deposited. At its mouth, if wide, which is most generally the case, the greater portion of the suspended matter is thrown down, especially at each change of the tide, when the impetus or force of the current is at a minimum, and, for a few minutes, destroyed. Hence arise what are called the *deltas* of rivers—so named because the deposit takes the form of the capital letter $\triangle$, in Greek—the stream opening out into two or more branches, and depositing the solid matter at its mouth, in the form thus represented. India, as at the Ganges, &c.; Egypt, as at the mouth of the Nile; and at numerous other places where rivers run into the sea through any extended length of country, the soil and other matters are conveyed downwards, and form tracts of surprising fertility.

Rivers that overflow their banks periodically, as the Nile, and occasionally, as all rivers do, have a great influence in fertilising the soil, and forming alluvial beds; and in many cases, even after years or ages, the adjacent banks retain their fertility, through the enormous amount of fertilising matter that is thus spread over the surface of the land, and the open kind of soil which is simultaneously deposited. Thus the banks of the Thames, at one time covered for a long distance inland, possess some of the finest soil for the growth of many kinds of crops. The annual overflow of the Nile, however, is perhaps the most striking instance of the kind in the world. The delta of that river, or the cultivated plain of lower Egypt, is about eighty miles from east to west, with a length of about ninety miles from the forking of the river to the sea. The whole country, after an abundant inundation has subsided, is covered with plantations, fields, orchards, and other evidences of the fertilising influence that has been in action. "The rise of the river, caused by the periodical rains of Central Africa, commences in June, and

continues to increase till September, overflowing the low land along its course; and the Delta then wears the appearance of an immense marsh, studded with islands, villages, towns, and plantations just above the water. About the end of November, the water having receded, most of the fields are left dry, and covered with a new layer of rich brown slime. The land is then placed under cultivation," and soon puts on the appearance of a "delightful garden, smiling with verdure, and enriched with blossoms." In the great plains extending between the Caspian Sea and the Sea of Aral, areas of great richness exist, produced by causes identical with those just described. Similarly, along many of our large European rivers—the Danube for instance—some of the finest corn, fruit, and other produce-bearing soil is to be met with.

Such a geological condition is not only advantageous, in its chemical constitution, to the agriculturist. It has the additional recommendation of requiring the expenditure of little power to put the soil into cultivation. Unlike the clay and rock, this is ready, from its softness, to receive almost the slightest impression. The roots of plants readily find their way between its solid portions, the mass being generally very porous. Hence it may be summed up, if the climate be favourable, in most cases, when properly drained, as presenting every circumstance that can naturally assist the operations of successful farming.

Although we shall have eventually to examine more fully into the cause of the fertility of such soils, a small table, illustrating the chemical composition of some of the most noted, may impress on the minds of our readers the immense advantages, in a fertilising point of view, that the alluvium (or washings down of rivers) possesses. In the following table, the mud of the Nile, producing a great variety of crops, from rice upwards—that of the black earth of the plains between the Caspian and Aral, called Tchornozem, producing an enormous quantity of wheat, feeding between twenty and thirty millions of persons, with an annual export equal to double that number of bushels—the cotton-growing soil of India, called Regur, producing, in succession, a crop of cotton and two of corn for the last 2,000 years (all, indeed, enormously productive for centuries);—these are compared, in chemical constitution, with the best grazing soils of Devonshire and Cheshire. Simply giving the particulars in numerical value, the reason of the fertility, with a description of the relative value of each constituent, will subsequently be afforded.

Of course certain allowance must be made, specially, in favour of the heat and moisture of the climate, in respect to the three first kinds of soil here named; circumstances at all times highly affecting fertility. Still, however, the character of each of them is so great, in a chemical point of view, that, making every allowance for climatal conditions, the productive power of such alluvia is very remarkable, and highly instructive to the practical agriculturist.

Constituent.	Nile Mud.	Tchornozem.	Regur.	English Red Marl.
Silica	42·50	75·00	48·20	70·20
Alumina	24·25	9·09	20·30	19·20
Magnesia	1·05	——	——	——
Carbonate of lime (chalk)	3·85	small	16·00	0·40
Carbonate of magnesia	1·20	?	10·20	——
Oxide of iron	13·65	5·56	1·00	6·00
Water and organic matter	13·50	6·95	4·30	4·10
Chloride of sodium (or common salt)	——	——	——	0·10
	100·00	96·60	100·00	100·00

Another and common form of loose deposit is that of *Diluvium*, also produced by the action of water, but highly different in its value as a producer of plants. Diluvium is the deposit occasioned by violent and sudden torrents, arising generally from heavy falls of rain or snow in mountainous districts, the waters from which sweep with impetuous course, carrying rocks, stones, &c., with them, and depositing these in masses, irregularly spread, and often exceedingly harmful to the farmer, as making, literally, stony instead of good ground. In the neighbourhood of the mountain districts of Scotland, frequent instances of this may be met with. Indeed, we have seen fields so covered with round granite stones, interspersed with coarse grass and herbage, as to present, at a distance, the appearance of a field in which turnips had been recently pulled up. Not that diluvium has no beneficial object or consequence. On the contrary, it frequently brings down some requisite of the soil, that any frost and moisture, in the course of time, will turn to good account in improving the ground. At the same time the farmer generally would prefer its absence, for reasons already explained. In many places, the quantity of stones that may thus be gathered from a field suffice to build partition walls, in the north of England and Scotland, in place of the more sightly and picturesque hedges of thorn, beech, &c., so common and pleasing in the midland counties and south of England, and that add so much to the beauty of its scenery.

In the preceding remarks we have not attempted to describe all the various geological formations that are under, or constitute in their *débris*, the fertile soil of our islands. It has been rather intended to point out chiefly such as are best known for their valuable properties to the farmer. But many of our readers may desire a brief epitome of the geology of Great Britain; and the following, chiefly the result of personal visits to the parts named, may be of interest. It commences with what are now considered as the oldest rocks, and ends with beds of the newest formation.

In Wales, Cumberland, and the south of Scotland, lower Silurian fossils may be found; and upper Silurian in Wales, Ludlow, Wenlock, and Shropshire generally. The old red sandstone abounds in Devonshire, Cornwall, and many parts of Scotland, in some counties of which it forms some splendid scenery. Devonshire, Derbyshire, Yorkshire, North Wales,

Scotland, and Ireland, are largely interspersed with carboniferous and mountain limestone; adjacent to which are the coal-measures, extending, more or less, from the Severn, in the south of England, through the midland counties; thence, right and left, respectively, to Durham and Lancashire, stretching, in Scotland, from the mouth of the Forth, on the east, to that of the Clyde, on the west. We need scarcely state that it is from the coal-measures our valuable mineral fuel is obtained.

The new red sandstone occurs in Devonshire, North Wales, Lancashire, Yorkshire, Cumberland, Worcestershire, and Cheshire. Lias is found in Somersetshire, on the north coast; Lyme-Regis, in Dorsetshire; also in Gloucestershire, Leicestershire, Yorkshire, &c. The Oolite is characteristic, or is found at Bridport, Leckhampton, Minchinhampton, Weymouth; also in Oxfordshire, Cambridgeshire, Huntingdonshire, Lincolnshire, and Portland; being the substance of which the celebrated building-stone of the latter name is composed. The Purbeck beds, Hastings Cliffs, and the neighbourhood of Tunbridge Wells, represent the Wealden deposits, to which Petworth marble also belongs. Greensand and Gault are variously distributed.

Arriving next at the lowest natural deposit now immediately available on its site for agricultural purposes, we perceive the cretaceous or chalk strata extending from Beachy Head to the Yorkshire coast, passing through Hertfordshire in a north-easterly direction.

The Tertiary strata are amply represented by the London basin, the soil of the Isle of Sheppey, and some parts of the counties of Essex, Suffolk, and Norfolk. On all or any of these last comes the alluvial deposit, as in the beds, banks, and mouths of rivers, which we have already pointed out as the most fertile of all the soils found in any part of the known world.

The igneous rocks, or those that have been formed by the fusing action of fire, occur indiscriminately; that is, although they are only found in certain localities, that position is accidental, and subject to no fixed geological law; for a granite or trap rock would be just as much in place, if protruding through the tertiary strata of the London basin, as they are in Kirkcudbrightshire, or some of the Grampians in Scotland. Not so the rocks that have been previously described, and which are considered to have been formed by the gradual deposition of their mass from water. They occur in regular order one above the other, with occasional exceptions; and, as such, the laws of their formation have not only been accurately studied, but such general principles have been arrived at, that in their application to agriculture, mining, draining, and other operations, are of the highest scientific and economic importance.

Having thus briefly epitomised the chief geological features of Great Britain, and, by implication, although not in detail, of Ireland, we may next take a general survey of England and Scotland, so far as their geological aspect affects agriculture.

First we may notice that, although at the same sea-level, the west coast of Great Britain is warmer than the east—the former having the advantage of the heating effect of the Gulf stream that crosses the Atlantic to our shores, whilst the east of our island is cooled by the breezes from the Steppes of Russia—yet the major portion of our agricultural operations is carried on in a line east of the range of hills that, commencing in Cornwall and Devonshire, extend in a northerly or a north-easterly direction, thence as far as the Grampians in the north of Scotland—a line or ridge of hills that has been expressively called the "back-bone" of our island.

But a moment's reflection will at once show the reason of this. *West* of the line to which we refer, as in Wales generally, and Cornwall—say, for example, from the Land's End to the mouth of the river Dee, in Cheshire—the country is exceedingly hilly as a rule, and, consequently at a great elevation above the sea-level, so that really the temperature is greatly reduced on the land, owing to this elevation above the sea. For distances near the earth, an average fall of one degree of Fahrenheit's thermometer occurs for each 300 feet of elevation; but this rule is liable to certain exceptions, as shown by the results of Mr. Glaisher's balloon ascents some years ago. It hence follows, that with an irregular and comparatively barren country, richer in minerals beneath the ground than in plants on it, agriculture is but partially carried on west of the ridge of hills alluded to.

On the east, however, of this ridge or back-bone, the conditions are very different in respect to the agriculturist. The land descends with a gradual decline to the south-east of Yorkshire, to the coasts of Lincolnshire, Norfolk, Suffolk, &c., in most parts of which it is but little above the level of the sea. The whole of this area, bounded west by the "back-bone," north by the Yorkshire hills, east by the German Ocean, and south by the English channel, is generally fertile, and productive of excellent crops of grass, corn, &c., interspersed with numerous rivers, containing, consequently, much alluvial soil; and taking questions of climate and level into consideration, is as favourable a locality for agricultural operations as any other in the world. On the north-west, portions of Lancashire stretch towards the Irish Sea, and, in most respects, resemble various parts of the east coast just described, although comparatively little corn is grown in that district.

It is not for us here to enter into any further description of the geological conditions of these islands, as sufficient has been said to convey a general idea of the subject. When we have to examine the nature of soils, the manures they require, and other similar matters, a more minute inquiry may then be made into many details now omitted to be noticed.

We may gather, however, from the preceding, that our islands generally are most highly favoured, in their geological conditions, for agriculture—far more so, indeed, in respect to variety, than any other part of Europe of similar

area, if we except the north of Scotland, beyond the Grampians—a comparatively small area; but include the rich land of the south of Scotland, as found in some parts of Perthshire, and the eastern coast; the Lothians; all Scotland south of the Forth, to the Tweed on the east coast; Ayrshire, Dumfries-shire, and neighbouring counties; in all of which, to a greater or less extent, agriculture, despite many opposing circumstances, has attained an astonishing degree of perfection.

Chemical Conditions.

Of all other arts, as we have already shown, agriculture is most dependent on chemistry. The seeds which the farmer sows undergo chemical changes immediately on germinating; and the whole growth of the plant, to the moment of its being reaped, is simply a progress of changes, by which inanimate matter is converted into organised forms. The soil itself, in which the seed grows is incessantly subject to chemical changes, not only during its assimilation into the parts of the growing plant, but also as it rests apparently quiescent in the field. There even some portion is undergoing solution, or becoming soluble, ready for the farmer's behests, if he know how to properly avail himself of its valuable properties.

Much as we now know of the constituents of the soil, and the new combinations it is capable of forming, still a measure of uncertainty exists in respect to many questions, simply because we are so ignorant of the nature of vital force, however much we may theorise on the subject. Thus we can readily understand how flint powder, mixed with carbonate of potash, and then heated red-hot, produces a soluble form of one of the most insoluble substances in nature —silica. But to produce the same result on sand or clay, by the cold method of solution in the laboratory, to any appreciable extent, and under the most favourable conditions, is yet a problem to be solved by chemistry. Similarly we know, by chemical analysis, that the major part of bone is formed of phosphate of lime; but physiology has yet to explain how it is that bone is, as a rule, only formed in the body of animals at the proper part, and not generally diffused throughout the system.

These remarks must not, however, be considered in any other light than that for which we make them; which is, to warn those of our most sanguine readers, that the extent of our chemical and scientific knowledge generally is limited, as are also some of its applications. To expect an entire solution of all difficulties justly referable to philosophic discussion, would be as unwise as to hope for the discovery of the philosopher's stone of the alchemist. Nevertheless, we can approximate to truth so closely as to leave a very narrow margin of error.

Chemists have universally agreed to a definition of *ultimate* and *proximate* elements in all matters pertaining to the analysis or constitution of plants. By the first term, ultimate, we mean the impossibility of obtaining from any body anything different from itself *out* of itself. Thus, do what we may with iron, it only affords us iron; although, if it be united with other bodies, we may reckon its new products by scores. By an ultimate element, we therefore mean a body that has defied all our efforts, up to the present time, to resolve it into simpler forms. Of these, chemists have discovered about seventy; comparatively few of which, as we shall subsequently see, enter into the constitution of animal and vegetable substances.

But a *proximate element* is not so simple. Thus, most animal and vegetable substances contain albumen, caseine, and fibrine, either in identical or analogous forms. In such a light we can view the proximate elements of milk, eggs, meat, peas, beans, &c., in a much more simple, or, at least, more readily-understood manner, than would be the case if we were to refer these proximate elements to the ultimate analysis. For example, albumen, caseine, and fibrine all contain hydrogen, oxygen, nitrogen, and carbon, but in slightly different proportions. The white of an egg, for example, consists of, and therefore resembles, albumen in all its forms; if we add an acid, or a little rennet, to milk, we obtain caseine in the form of the curd, of which cheese is made; and, lastly, if we whip up blood with some twigs, we can separate its fibrine in the form of fine fibres; hence its name, just as that of caseine is derived from cheese, and albumen from the white of an egg—the word *albus*, in Latin, signifying white.

Our unscientific readers will, therefore, at the outset, understand the distinction made by chemists between *ultimate* and *proximate* elements; and it will be important that such distinction be kept in mind.

The ordinary operations of the farm, apparently simple though they may be, really consist in converting these ultimate into proximate elements. In other words, whether the farmer sows corn-seed, or grazes cattle, he converts, for the benefit of the community at large, together with his own profit, such ultimate elements as carbon or charcoal, hydrogen and oxygen (the constituents of water), and nitrogen (an essential constituent of the air, nitre, ammonia, &c.), into flour or flesh, which are constituted of the proximate elements, directly or indirectly, just described. We omit the discussion of mineral matter, such as iron, lime, &c., that will eventually come under special notice.

It is evident, therefore, that the farm is a chemical laboratory on the largest scale, whether the farmer knows it or not. The more he is acquainted with, and appreciates the fact, the greater probability there is of his carrying on operations to a successful result. For example, if he graze largely, then he will know how so to proportion the food of the animal as to produce an excess of either fat or lean, or a medium amount, as he may desire. In respect to his crops, he can quickly decide that one part of his farm will produce potatoes; another turnips, mangold, &c.; and that he may convert another into arable land, for corn crops; whilst a fourth may be better kept as pasturage.

But, still further, not only deciding as to the best mode of parting out his farm, he will also decide on the most suitable means, by machines or otherwise, of carrying out his intentions. To assist him, in respect to chemical science, will now be our business, to some humble, but, we trust, useful extent.

We shall first treat of such elementary bodies as are most essential to the growth of plants; and, of all others, that most important is—

Oxygen.—The simplest form in which chemists have hitherto collected or examined this body, is that of a gaseous condition; just, in fact, in the same form as the air we breathe. It forms about a fifth of the bulk and weight of the atmosphere that surrounds our globe; and is a respiratory agent, not only of animals, but also of plants. Of water it is a constituent to the extent of eight parts out of nine by weight; that is, every nine pounds of water contain eight pounds of this element, united with one of hydrogen—a gaseous body, of which we shall presently have to speak more fully.

The great effect of this agent in nature is that of breaking up and destroying previously organised substances. Of course, we here restrict ourselves to those conditions which affect our present subject alone; for the operation of oxygen is universal: so much so, indeed, that in combination in the animal, vegetable, and mineral kingdoms, it forms, together with its presence in air and water, from one-half to two-thirds of the mass of matter in the globe. The name is derived from the Greek words, signifying *acid-maker*, first given it on the supposition that it is a constituent of all acids—an idea which we shall presently see to be erroneous. United with metals, it forms oxides; thus alumina, the base of alum, clay, &c., is an oxide of aluminium; the red colouring matter of soils is generally an oxide of iron; magnesia and lime, common constituents of soils, are respectively the oxides of the metals magnesium and calcium.

It has been already noticed that oxygen is the respiratory agent of plants and animals. The latter take it into the lungs, where it oxidises the carbon, or charcoal, that the venous blood contains, producing carbonic acid. In this form of combination oxygen is inspired by the underneath portion of the leaves of plants, which retain the charcoal, decomposing the acid, and returning its oxygen again to the air, fit for breathing by animals. The plant, therefore, revivifies what the animal had poisoned.

But not only in respect to its vital powers is oxygen of so great importance. As soon as death, or loss of vitality in the whole or part of a plant or animal occurs, this element becomes, aided by heat and moisture, in active exercise. Decomposition of the tissues commences, and new forms of combination arise. The animal becomes converted into carbonic acid gas and ammonia, and similar changes occur with the remains of the dead plant. Thus, when the excrements or dung of animals, and the straw on which they have stood, are exposed to the air, all the organised matters become broken up by the action of atmospheric oxygen; and thus a most valuable manure is produced for the land. When there deposited, the chemical action still goes on, and food is supplied for the plant growing on the soil.

Numerous other important offices are performed by oxygen in nature; but, as we shall have constantly to notice its effects, we may content ourselves, for the present, with what has been here stated respecting its general properties.

Chlorine is another element that must be noticed as a constituent of the soil, and apparently an essential one in plants and animals, where it is chiefly found in the form of common salt, which is a chloride of sodium—that is, a compound of chlorine and the metal sodium, the base of the well-known alkali, soda. Common salt, chloride of potassium, and some other chlorides, are generally present in minute quantities in the soil. When seaweed or fish is used as a manure, the quantity naturally present is, of course, largely increased. Common salt is found in the blood of most animals, and many of the domestic kind are fond of it. It necessarily follows, therefore, that as it is a constituent of the blood, it must, in the majority of cases, find its way to the animal from the soil. The reason that salt is so essential to animals is, that it affords, with hydrogen, hydrochloric acid, or, as it is sometimes called, muriatic acid, marine acid, or spirits of salt. Without this in the stomach of animals, digestion could not go on, for it affords a primary constituent of the gastric juice, the great solvent, there, of animal and vegetable food.

Iodine and *Bromine*, that are analogous to the preceding, are of little consequence, either in the soil, plant, or animal, so far as is at present known. They are both products of sea-water; and hence, if seaweed be used as a manure, they must necessarily, in such a case, be added to the soil temporarily or permanently.

Sulphur is an essential element of some of the plants grown by the farmer. Thus the *Cruciferæ*, or plants of the cabbage tribe, all contain sulphur, as do mustard and the onion family. Hence the extremely offensive smell of these, as they rot or decompose. Sulphur is also found in animals; hence, for example, the reason why a silver spoon turns black when used in eating an egg, the sulphur of which combines with the silver to form what is called a *sulphide*.

The chief form in which sulphur is found in the soil and plants is as a *sulphate*. A sulphate is a combination of sulphur and oxygen, forming sulphuric acid, or oil of vitriol, that, uniting with a base, affords a sulphate. For example, plaster of Paris is a sulphate of lime; Epsom salts is a sulphate of magnesia. One sulphate, that of ammonia, is a useful manure, now largely manufactured from gas liquor (see *ante*, p. 348), but formerly conveyed to the land in the form of coal-soot. Coal contains both nitrogen and sulphur, as a rule; and, as it burns, the sulphur is converted into sulphuric acid, and the nitrogen into ammonia, which, uniting together, afford the sulphate of ammonia.

Fluorine occurs in minute portions in plants. Its use in the animal economy is to form the hard enamel of the teeth, in the form of a fluate of lime, familiarly known, in masses, as Derbyshire spar, in which form it is generally abundant in nature.

Recapitulating these active agents in effecting combinations of the soil, we have noticed oxygen and oxides, chlorine and chlorides, sulphur, sulphides, and sulphates, as of the greatest importance to agriculture ; whilst iodine, bromine, and fluorine are of more rare occurrence, and sparsely required both by plant and animal.

We next turn to three elements, apparently of a passive nature—by which we mean that they are rather acted on than active. Not that this idea is philosophically correct ; for, whilst we speak of the powerful influence of oxygen, it would be just as reasonable to invert the statement, and ascribe the same power as exercised by hydrogen, nitrogen, and carbon on oxygen, instead of the latter on them. We shall, however, retain the popular idea on the subject, because it saves much circumlocution, and will enable us to avoid the discussion of philosophical theories of no value whatever to the agriculturist.

Hydrogen is a most important element in nature. It is a constituent of all plants and animals, and nearly all their products. One-eighth part, by weight, of water, is composed of this element. With chlorine it forms hydrochloric acid, already noticed ; with sulphur, sulphuretted hydrogen, or hydrosulphuric acid, that offensive gas produced in drains, decomposing manure, &c. ; with nitrogen it forms ammonia, as we shall explain. It makes up about one-sixteenth part of the tissue of wood, and forms one-thirteenth part of the weight of dried muscular flesh. It is afforded to the plant by the water and ammonia of the soil; independently of the water that is conveyed mechanically into the plant to serve as a solvent of its juices. It is an essential constituent of starch, sugar, the gluten of wheat ; and, indeed, as before mentioned, of almost every plant and animal product. For example, in every 32 lbs. of potato or flour starch, hydrogen is present to the extent of 10 lbs. In animal substances, such as albumen, caseine, and fibrine, (see *ante*, p. 354), it generally exists in the proportion of 7 per cent. In its impure, or, more properly, combined form, it is present in coal-gas and tallow, oils, fats, &c. ; in the first as a gas, and in the three latter as a solid or liquid, until they are burnt, when it becomes a gas, united with carbon.

Nitrogen.—This element is one of great importance in the economy of nature, and is an element of the most valuable manures. United with hydrogen it affords ammonia ; or forms, in guano, the decomposing urine of animals, and is the cause of the pungent smell of stables and dung-heaps. As already noted, it forms four-fifths of the weight and bulk of the atmosphere. It is a necessary constituent of such animal substances as albumen, caseine, and fibrine, which contain it, respectively, in the proportion of about 15 per cent. Except in the form of atmospheric air, it is always found in combination, especially in nitrates and salts containing ammonia. Thus, sulphate of ammonia contains it. Nitre, saltpetre, or, as it is termed by chemists, nitrate of potash, is composed of nitric acid—a compound of one proportion of nitrogen to five of oxygen—and potash. Nitrate of soda similarly contains it ; and, consequently, is a valuable manure. As animal bodies, and some of the vegetable kind, decompose, they emit the nitrogen generally as ammonia ; hence the value of guano, stable dung, artificial animal manures, sewage, &c., as an addition to the land ; the nitrogen required by the plant and animal being thus conveyed to the soil. Wheat, peas, and beans are eminent examples of what are called *nitrogenous* substances ; that is, those containing nitrogen as an essential element. In wheat, whilst the starch has no nitrogen, the gluten, or glue-like matter, possesses it. Similarly, in peas and beans, the legumin is essentially composed of nitrogen. So necessary is this element to animal life, that a person fed abundantly on pure starch will die of starvation, because of the absence of nitrogen ; whilst wheaten bread, peas, and beans, containing it, may be safely substituted for meat, as food of the most nourishing kind.

From these considerations, it is a matter of no surprise that so much has been done of late years to supply the farmer with nitrogenous manure ; and the discovery of the absolute necessity of such to produce good crops of wheat, oats, peas, &c., has led to extensive manufactures of a great variety of those mixtures or compounds. This is not the place to enter into any description of them ; but, we may add, that their value is now chiefly reckoned according to the amount of nitrogen they contain.

Carbon, like the two preceding, is a characteristic element in plants and animals ; and is, consequently, of great importance in an agricultural point of view. As a solid, in its purest form, it constitutes the diamond, which is solely crystallised carbon. In its impure form, it is seen in coke, anthracite coal, charcoal, &c. Every thirty-two pounds of starch or sugar contain twelve pounds of pure charcoal. This may be readily separated, as a black mass, by pouring strong sulphuric acid into some syrup made of white sugar, when, owing to the attraction that the acid has for the water of the sugar, the carbon or charcoal will be set free. Every thirty-two pounds of starch are composed of twelve pounds of charcoal and twenty of water ; whilst sugar contains the same amount of charcoal with eighteen of water—a fact, showing the importance of carbon, hydrogen, and oxygen in the plant. In animal substances, albumen, caseine, and fibrine contain, on an average, $53\frac{1}{2}$ per cent. of carbon ; hence it is, that, when wood, bread, flesh, &c., are charred, they turn black, the carbon or charcoal being set free.

The most important form of carbon to the farmer is that of carbonic acid, in which one proportion of carbon is united with two of oxygen. This acid, as a gas, is familiarly

known as producing the froth of porter, ale, some wines, soda-water, &c. It is abundantly produced by the breathing of animals, who convert the carbon of the venous blood on the lungs into carbonic acid gas; and, also, by almost every form of combustion. It is present in the air in variable, but small, proportions, not usually exceeding the $\frac{1}{1000}$th part; but, as already stated at p. 355, *ante*, the gas performs an important office in providing the carbon constituting the solid portion or wood of the plant. Breathed in even moderate proportions, it is deadly poisonous. The decomposition of the dung-heap is attended with the production of a large quantity of carbonic acid gas, which, if allowed to accumulate in deep pits, might cause fatal accidents; because, being heavier than air, it soon collects in such places: hence the danger of descending into pits and wells that have been long closed, without first introducing a lighted candle. If, under such circumstances, the flame be extinguished, it is a sure sign that death would follow an attempt to descend into such a place. It forms the chief constituent of the choke-damp of mines, that generally produces more fatal results than even the explosion itself.

To the farmer, the carbonates—that is, the compounds of this acid with a base—are of the chiefest importance. For example, chalk consists of carbonic acid and lime; every fifty pounds of chalk containing twenty-two of carbonic acid and twenty-eight of lime. In the soil this is an essential ingredient; the carbonates of magnesia, &c., are also present. In a good marl soil about 12 per cent. of carbon is present, in the form of carbonic acid, united with the lime as a carbonate.

Carbonic acid has a great solvent effect. For example, the clearest river-water, on being boiled, will deposit a yellow-coloured matter. If a strong acid be poured on it, gas will be given off, which is the carbonic acid. Now, in the cold state, the water contains an excess of carbonic acid, which holds the chalk it possesses in solution: but, on boiling, this excess of acid is driven off. In the soil, therefore, the carbonic acid of the air and water dissolves the lime present, and, conveying it in a soluble form to the roots of the plant, it is assimilated or converted into the substance of the plant. This interesting fact is thus easily illustrated:—Dissolve some caustic lime in cold water by constantly shaking up a small lump in the fluid. Let it settle, and pour off the clear, brilliant liquid into a clean glass. Then add a *little* soda-water, when the carbonic acid of this will unite with the lime to form chalk. Add more of the soda-water abundantly; then the chalk just formed will be all dissolved, and the liquid will become transparent. Boil this, and the chalk will again be deposited. This simple experiment illustrates one of the most important operations in nature to the agriculturist, especially in regard to crops like peas and beans, for which lime is essentially necessary.

When chalk or limestone is burnt in the kiln, for the purpose of making it caustic, as a manure, &c., the carbonic acid is driven off; and thus 100 pounds of chalk will lose forty-four pounds of this acid, independently of the moisture and animal matter evaporated. As the lime thus rendered caustic is exposed to the air, it again absorbs carbonic acid, and returns to the form of chalk. Hence, when liming lands, the excess of carbon present is readily removed; forming first carbonic acid, and then uniting with the lime. Similarly, if a dead animal body be immersed in lime, its carbon will gradually be united with the lime. The formation of this carbonate is readily noticed by pouring some lime-water into a plate. In a few hours the surface will be covered with a thin film of a white appearance, which is chalk formed by the carbonic acid of the air, and the lime of the lime-water.

Phosphorus.—This element, which is analogous to sulphur in many respects, and in others to hydrogen and sulphur, is another important element to plants and animals. It is never found free in nature, unless produced during decomposition, as in crabs, &c., or possibly emitted by some minute creatures, causing the beautiful phosphorescent appearance, occasionally seen at night on the sea. With oxygen is formed phosphoric acid; and this acid, by union with bases, affords *phosphates*, in which form the element exists in the soil in plants and animals. The chief phosphate is that of lime. It exists in the bones of animals, in the proportion of about 53 to 58 per cent. of their weight. The ashes of plants, as the seed of wheat, peas, beans, &c., contain from 90 to 97 per cent. of phosphate of lime, indicating the presence of from 15 to 20 per cent. of phosphorus. All grasses, and every plant and seed used for food, contain phosphates, as does also the milk of women, and other suck-giving animals. Phosphate of lime, indeed, is absolutely essential to form the bone; and hence children kept to the breast after the milk has deteriorated in respect to phosphate of lime, or fed on food equally deficient, do not receive sufficient solid matter to form bone, which, consequently, is really only cartilage or its equivalent. It is considered that the phosphates in the body of a healthy adult, weigh about one-fifth of the total weight. Phosphates are found in the shell of the crab, lobster, crayfish; in egg-shells; in a mineral called coprolite, apparently the fossil dung of animals; in guano, &c.

The importance of phosphates to the soil is therefore manifest; and hence, of recent years, every effort has been made to supply the farmer abundantly with them. The chief present source is that of phosphate of lime, obtained from bones. The latter are either spread in a crushed or pulverised condition on the land, or else a "superphosphate" is made by adding sulphuric acid to crushed bones, by which a portion of the lime is separated from the phosphoric acid, and a very valuable phosphate manure produced.

We next turn to a variety of substances, generally reckoned as the mineral constituents of the soil, plant, or animal; although it is difficult to draw any such distinction; for all the pre-

ceding substances, gases, &c., are discovered in a mineral form in the soil. Still the conventional distinction exists; and, moreover, it is, perhaps, justified on the ground that all other compounds that have to be described are obtained as *ash*, or solid matter, by burning plants or animal substances; whilst all the preceding, excepting when in combination with earths, &c., can be driven off as gaseous or volatile matters, either separately or in combination; thus oxygen and hydrogen fly off as water, hydrogen and nitrogen as ammonia. Sulphur and phosphorus are volatile, *per se*, and in many of their combinations; as are also chlorine, iodine, bromine, and fluorine; whilst carbon is dispelled as carbonic acid in a variety of ways. The following substances, under all ordinary circumstances, are of a more fixed nature, and are generally found in combination with some or all of those that have been described.

Potass, Potash, Pearlash, Potassium.—The three first are equivalent names for the same substances, composed of oxygen and the last-named substance, a metal known as potassium, or kalium. Commercially it is obtained by burning inland herbaceous plants, which abstract it from the soil; hence the name of pearlash, that is commonly applied to it in commerce. Most plants contain it, but in very variable proportions; and those that largely require it, will not grow in soils destitute of the alkali. Primarily, potass is derived from the decomposition of felspar, and other igneous rocks—a source that has been in part employed to obtain potash commercially. Some of its salts exist in the blood, milk, and urine of animals, chiefly as chloride of potassium. In animals feeding on herbs, potash salts are generally abundant. In human urine the sulphates of potass and soda are present.

There is little doubt that the presence of potass is essential to the solution of silicious matter in the soil—a substance of which we shall have more fully to speak hereafter. The wheat and straw of about a ton of the seed contains nearly fifty pounds of potassium, in the form of its salts.

Soda, Sodium.—This, an alkali, like the preceding, and analogous to it in most respects, is abundantly disposed in nature, as the chloride of sodium, or common salt, and in the form of sulphate, carbonate, and phosphate of soda. Formerly it was called the mineral alkali, in distinction from potash, termed the vegetable alkali, because soda was obtained from the ashes of seaweeds, and derived from salt they contain; but, of course, such distinctions are simply chimerical. Its present commercial source is salt, as obtained from the mine. On an average, a ton of wheat, with its corresponding straw, abstracts about five pounds of sodium in the form of its salts; and grass and clover about twelve pounds. Nitrate of soda—a combination of the alkali with nitric acid—is found native in some parts of the world; and, of late years, has been largely used as a manure.

Ammonia, another of the alkalies, has been described with nitrogen, at p. 356, *ante*.

We next turn to the earths, apparently the most important elements of the soil, although mostly so from their mechanical texture, as enclosing various salts, &c., and containing the root of the plants as a bed, rather than from their chemical characteristics; for, after all, carbon, hydrogen, oxygen, and nitrogen are of infinitely greater abundance in plants and animals generally, excepting, however, in the bones of the latter.

Under the head of Earths, are included silica, alumina, lime, magnesia, baryta, strontia, lithia, and others of rare occurrence; but, for the purpose before us, attention may be confined to the four first-named, as the rest little, if at all, affect the vegetable and animal kingdom; and, consequently, so far as at present known, are not of the least importance to the agriculturist.

Most of the soil of all parts of the world has its bulk formed of silica, alumina, and carbonate of lime—the latter being variously present, and always in much less quantities than the two first, except in chalk or marly soils. Magnesia, too, is of comparatively trifling occurrence, except in special localities; and in the majority of soils is, perhaps, absent. Reference to p. 352, *ante* (where a table will be found, giving an analysis of some of the richest soils in the world, in ordinary cultivation), will give the reader an idea of the relative consequence or value of the respective earths.

Silica, or the matter of pure flint, is very universally distributed. It is familiarly known as the ordinary flint, and in sand; in both of which, however, it is mixed with a small quantity of oxide of iron. By reducing either flint or sand to powder, mixing this with three times its weight of carbonate of potash or soda, and fusing the mixture at a red heat in a crucible, a solid may be obtained, soluble in water. On adding hydrochloric acid to such a solution, and evaporating to dryness, a white gritty powder is obtained, which is pure silica.

In vegetable and animal economy, silica is of

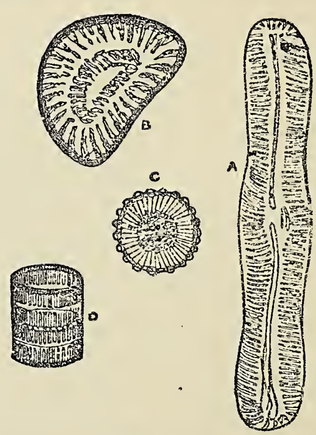


Fig. 315.

the highest importance; and, like all provisions of nature, it is most abundant when most

wanted. In guano, for example, it assumes some curious forms, and the preceding cut represents some of them. A and B are silicious skeletons of *Diatomaceæ;* C, D, are silicious forms, obtained from rich Virginan soil in the United States of America.

It will be noticed that many grasses have, at the back, shining particles. These consist of crystallised silica. In the annexed cut, there is

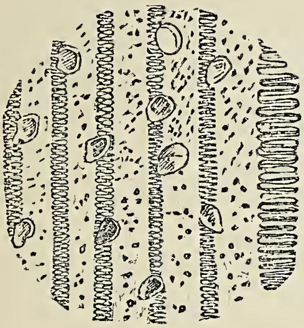


Fig. 316.

represented the silicious cuticle of wheat, showing the cups for the insertion of the hairs; and also the spiral vessels of the straw.

Silica answers, in many plants, the same purpose that bone does in animals. It affords, in fact, the back-bone, and gives them stability to resist the action of the air, or any mechanical cause that might injure their structure. Perhaps one of the most beautiful forms in which silica is thus found, is that of common Meadow grass, the *Festuca pratensis,* the silicious coating of which is represented in the annexed cut.

Fig. 317.

The necessity of silica, especially in cereal crops, is evidenced by the large amount that is abstracted from the soil by them, especially in the straw. Thus, 1,000 parts of each of the following straws of plants usually produced in agriculture, take from the land the amount of silica stated :—

Oat straw	45
Barley ,,	$38\frac{1}{2}$
Wheat ,,	$28\frac{3}{4}$
Indian corn (maize)	27
Pea	10
Potato-tops	8
Beans	$2\frac{1}{4}$
Bean straw	2
Cabbage	2
Buckwheat	1

The most advantageous form in which silica can be presented to a growing crop, is that of the minute skeletons represented in Fig. 315, *ante,* because in that greatly divided condition its solution is most readily effected. It has already been stated at p. 346, *ante,* that a state of solution is absolutely essential to the nourishment of the plant by its roots; and as silica is, perhaps, the most insoluble substance in nature, under all ordinary circumstances, the most minute condition of division is that which most facilitates its absorption by the plant, and its beneficial result for the farmer. It thus follows that straw is an excellent addition to land deficient of silica. As shown by Fig. 316, *ante,* the grasses to which wheat belongs contain silica in a minute state of division, and crystallised. Hence when the straw spread on the land decomposes, the silica is set free at the service of the growing plant.

Silica is an oxide of silicon or silicium, the former name denoting the analogy of its base to carbon, and the latter its metallic analogies. But it is uncertain to what group we should assign silica and silicon. We have preferred to rank it amongst the earths on account of its general analogies to them. The purest form in nature is rock crystal and quartz; and it is the constituent of nearly every gem or precious stone except the diamond.

Alumina, Aluminium.—Alumina is the oxide of aluminium—a metal now coming into extensive use for ornamental and useful purposes, and although known for many years, only recently produced in quantities permitting of its considerable use in the arts, &c.

Alumina is readily obtained from alum, by adding to a solution of that salt one of carbonate of ammonia. After washing and drying, it is a white powder, insoluble in water, but readily dissolved in a solution of potash or soda. If, however, it be heated to redness, its solubility, in these agents, is destroyed. It proves, next to silica, the chief constituent of all kinds of clay. Silica being really an acid—the silicic—unites with the alumina to form the silicate of alumina, which constitutes, together with oxide of iron, the ordinary clay of our fields; the other substances so numerously found therein being really accidental in their presence.

As already pointed out at p. 350, *ante,* clay is a chief constituent of all corn-growing soils under ordinary tillage; and yet it is not an important element in the constitution of plants, as will be seen by referring to the table given at p. 347, *ante,* showing the amount of abstraction of various ingredients of the soil. It would seem, in fact, chiefly to afford that mechanical condition essential to the maintenance of the seed in the ground, and also to support the lower part of the stem that proceeds from the seed during growth. The excess of clay is mostly more to be regretted than its absence; although, after all, alumina is generally present in all soils. Whilst silica has little adhesive power, alumina is rather characterised thereby; hence in the form of kaolin, for china ware, and common clay for bricks, &c., it is of the highest value. In the form of draining tiles, all our practical readers will recognise its importance.

Alumina is characterised by a great attraction for water, and a most retentive power, when

once in contact with it, that even a white heat cannot overcome. Hence, from this and its tenacity, it forms stiff, strong soils, that, if badly managed, are valueless; but, if properly tilled, invaluable. With plenty of capital at our disposal, we should much prefer a good stiff clay to most soils, provided sufficient fall for drainage, and an average climate (for England), could be commanded. By burning a portion, well ploughing or digging the rest, and working in the burnt clay, almost any amount of division of the soil may be effected. In many places it abounds with crystallised sulphate of lime (plaster of Paris); and this, burnt with the clay, tends to fix the ammonia, and affords, consequently, an excellent and greatly required nourishment for the plant. As already stated at p. 346, *ante*, we have succeeded in producing excellent bean crops by drainage, addition of chalk and sand to clay, that, under neighbouring management, had scarcely produced a weed, let alone a plant of any economic value. An average good clay land, if properly managed, is like a bank offering excellent security, but moderate interest: but the interest is regularly paid. Whereas, on what may be termed a fast soil (for we shall not call it a fertile one), some excellent crops may at first be raised; but, like banks paying large interest, with bad security, both principal and product quickly fail.

But much judgment is required in dealing with a highly clay soil. To plant potatoes, for example, in it, would be about as wise as attempting to grow pine-apples in the open air at Norway, unless it be first brought to a high state of division. The objection and the difficulties it presents are purely of a mechanical nature. By this we mean that it prevents the extension of the radicles of the plant in search of food: so much so is this the case, that we have frequently succeeded in dwarfing plants—that is, in reducing the size of their flowers—by simply packing their roots with clay as tightly as possible. On one occasion, cutting off all the flowers of a good pansy, we succeeded, by this method, in the same season, in producing another set of flowers, not one-tenth in area of those that had preceded them.

Any of our readers who have travelled observantly through our islands, cannot fail to have frequently noticed trees stunted and deformed in their growth. In numerous instances, especially in the neighbourhood of London, and London clay, this may be often noticed. The tree or plant flourishes very well until it reaches the pure clay bed, and there the further descending progress of the roots is entirely stopped. In the north of London, for example, we could point out some hundreds of elm and other trees, the roots of which have shot off horizontally, instead of descending, to a distance of thirty or forty feet in the surface soil. Some of them cannot be less than two or three hundred years old; yet, if taken up to the lowest root, they have not descended more than four or five feet.

Lime, Calcium.—Lime is an essential constituent of soils, and enters into the composition of all vegetable and animal products. It occurs, almost without exception, in the ashes of all plants. As the phosphate, carbonate, and fluate, or, in respect to the latter, more correctly the fluoride of calcium, it enters into the composition of the bony structure of all animals, from man to the lowest mollusc; besides also being found in the bodies of animals of still lower scale in nature, and destitute of an internal or external covering.

We have already said much on the chief salts of lime, under the head of Carbon and Carbonic Acid, at page 356, *ante*, in regard to chalk and limestone; in respect to the phosphate, in connection with phosphorus, at the same page; and of the fluate, or fluoride of calcium, when describing fluorine, at p. 355, *ante;* and have, therefore, to an almost needful extent, said as much as is requisite on that element, so far as its uses in vegetable and animal economy are concerned.

Lime, as a manure, is of essential service to the agriculturist. Applied in the caustic state it diminishes the presence of organic acids produced by an excess of decomposing or undecomposed vegetable matter on the land, facilitating and inducing their decomposition, and, at the same time, absorbing the carbonic acid and ammonia thereby produced. Sulphate of lime, especially, may be considered as a kind of storehouse for free ammonia in the field.

In chalk and limestone countries, lime-burning is largely carried on, not simply for the sale of the caustic article for building purposes, but almost equally for the farmer's use. It has the advantage, especially with sand, of lessening the tenacity of clay lands, and hence of increasing their fertility, both on account of chemical and mechanical grounds.

Marly soils are especially identified with the presence of lime in the form of chalk; and with a proper admixture of sand, clay, and vegetable matter, they are amongst the richest that are found in our islands. They abound especially in the south-eastern districts of England, and have already been generally dealt with, under the head of Calcareous Soils, at p. 349, *ante*.

Lime is an oxide of the metal calcium. When caustic it has an astonishing attraction for water; for during the process of slaking, the combination is effected so intimately and rapidly, that sufficient heat is afforded to set fire to wood. Hence carts and sheds containing fresh-slaked lime, often catch fire, if exposed to long rain. It is barely soluble in water, 700 or 1,000 parts of that liquid being required to dissolve one of lime; and it is more soluble in cold than hot water. It rapidly attracts carbonic acid when in the caustic state, being converted into the carbonate, or chalk. This, as shown at p. 357, *ante*, is soluble in excess of carbonic acid; and thus the lime is conveyed as a mineral nutriment to the plant. With silica it unites to form a silicate, in which condition it is found in mortar—that is, in part a silicate of lime. Hence old mortar is extremely useful as a manure when procurable. We have found it excellent for scarlet-runners, and other kinds of beans.

The presence of lime in water is the usual

cause of its hardness, whether in wells, ponds, or rivers. It may be here not out of place to mention simple means by which water, hard from the presence of much of the carbonate in solution, may be softened.

At p. 357, *ante*, a simple experiment was suggested, which was intended to illustrate the action of carbonic acid, in dissolving carbonate of lime by its presence in excess. Now in all water that is hard, owing to the presence of the carbonate, the latter is so held in solution. If, however, some caustic lime be added to such hard water, then the excess of carbonic acid will leave the chalk it held in solution, and attach itself to the newly-added lime, precipitating a portion of it as chalk. Thus the previously existing chalk in the water, and that newly formed by the method just suggested, will both be thrown down in an insoluble state.

Magnesia, Magnesium.—The earth magnesia is the oxide of the metal magnesium, now so popularly known as producing a brilliant light during its combustion. This earth is pretty generally distributed; but in some districts in England is quite absent from the soil, or, if present, it is so in exceedingly small quantities, that escape chemical analysis. It forms a constituent of magnesian limestone, in which it occurs as the carbonate; and it is only in the latter form that it is usually met with in soils. As the phosphate it is found in the human body, often being the cause of concretions in the bladder, as the double phosphate of magnesia and ammonia. By reference to p. 347, *ante*, it will be found amongst the constituents of wheat, as it is also of grass, oats, turnips, &c. It does not, however, usually command the attention of the farmer in the application of manures; and hence it would appear, although frequently present, not to be of essential consequence as an element of the soil. The English red marl of Devonshire and Cornwall, that affords rich pasturage, seems, according to the analysis given at p. 352, *ante*, to be destitute of it; and we have analysed other good corn soils, that presented but a trace of magnesia. It is familiarly known as a product of medicinal importance, in the form of Epsom salts, so named from occurring in springs at Epsom; but commercially prepared by adding sulphuric acid to magnesian limestone. The phosphate constantly occurs in the chemical analysis of the ashes of vegetables. Wheat, rye, peas, and beans, for example, present it, and it also constitutes a portion of human blood and bones.

Passing from the earthy constituents of soils, plants, and animals, we next notice the combinations of metals proper that occur therein.

Iron.—This metal is almost everywhere diffused in nature, from the blood of man to, perhaps, every soil on the surface of the globe. Generally, it is found in the state of oxide, similar to the red rust common on iron that has been exposed some time to air and moisture. This oxide is termed the sesquioxide in chemistry; and consists of two proportions of iron united with three of oxygen. In this condition it is the cause of the red colour of clay after burning; and also of the blood of red-blooded animals, in which it is an important constituent. As the phosphate of iron, it is found in the ashes of wheat, rye, peas, and many other vegetable products. Of the ashes of some kinds of firewood it constitutes upwards of 22 per cent. In many parts of this country it is so abundant in the soil as to give it a red appearance. It is, however, a constituent of plants and animals, of which, it may be said, a little goes a long way. Thus, at p. 347, *ante*, we notice, that the proportion of wheat there stated, only abstracts from the soil about 3 lbs.; but even this small quantity, as the sesquioxide, has great colouring and other properties.

Manganese.—This metal may be briefly noticed, simply because it has been discovered in the analysis of some woods, and in the human frame; but generally its presence is so slight in soils as not to be discoverable by chemical analysis.

We thus find that the entire constituents of the soil, so far as chemical analysis has yet discovered, are restricted to less than one-fourth of the total number of seventy elementary bodies, now recognised by chemists; and, of these, the chief combinations of plants and animals are further restricted to the following—oxygen, hydrogen, nitrogen, carbon, sulphur, phosphorus, and lime. Indeed, taking the purely organic forms of plants and animals, the vegetable kingdom, in the greater portion of its products, only requires oxygen, hydrogen, and carbon, with an occasional presence of nitrogen; whilst the animal products are almost universally composed of variable proportions of oxygen, hydrogen, carbon, and nitrogen; the presence of the latter element being a characteristic of animal matter.

Simple and few, however, as are these elements constituting the mass of vegetable and animal substances, still the power they have of uniting in an almost infinity of varying proportions, permits of a nearly endless amount of combinations, utterly differing in chemical, physical, and other properties. This we shall see as we next pass on to consider the proximate principles of plants and animals; but, for a moment, we may illustrate this fact by taking starch as an example. Thus, by chemical means, we can convert starch into sugar, sugar into alcohol, or absolute spirits of wine, and this into ether. Sugar, again, may be converted into oxalic, acetic, and other acids; and so the three elements, by varying proportions of combination, produce not only the few that we have enumerated, but hundreds, indeed thousands, of others.

And here we cannot forbear remarking, especially to those who may, for the first time in the perusal of this work, be turning their attention to practical chemistry, that, although the number of different substances in nature appears limitless, still there is no body that has yet been analysed that cannot be reduced in its consideration to that of the union of a few elements, the properties of which are well known; and it is this simplicity of constitution that enables us not only to obtain exact results by analysis, but also to form theories dependent on the facts

thus obtained. For example, nothing could, at first sight, be imagined more complex than the soil of the field ; but, in the hands of the accomplished chemist, that complexity soon vanishes, and each constituent is gradually eliminated, and the proportion or weight of it present easily stated, absolutely or by per-centage.

Once having acquainted ourselves with the properties of each elementary body, and its chief combinations, we obtain a key that readily and accurately opens out to us the secrets of nature, and permits us to suggest or advise with tolerable certainty in any difficulty that may arise. It is for this purpose that the leading properties of all the chief *ultimate* elements entering into the constitution of the soil, plants, and animals, have been given ; and we shall now briefly, for the same reason, give some account of the leading *proximate* elements of the vegetable and animal kingdoms, commencing with those of plants.

Starch is one of the most important of these proximate principles in plants. It is composed of twelve proportions or equivalents of carbon, and ten each of hydrogen and oxygen ; and, consequently, we may simply look upon it as a compound of charcoal and water. It is found in all plants, and may readily be separated by bruising them in cold water, in which it is insoluble. Thus, wheat-flour, if put into a muslin bag, and washed in cold water, will part with all its starch, which may be collected in a basin. The proportion of starch in various plants, or their fruit, greatly varies. It is, per cent., as follows. In—

Wheat	60
Barley	48
Oats	40
Maize	60
Rye	51
Rice	74
Peas	37
Beans	36
Potatoes	$15\frac{1}{2}$
Parsneps	3
Cabbages	$\frac{2}{3}$

Here we notice a great variety in the proportions ; and hence, to a certain extent, depends the value of such articles of food.

Starch, as an object of animal food, although affording barely flesh and not bones, is of the highest value as a source of animal heat. It must here be remarked, that the lungs of warm-blooded animals correspond in their office to the furnace, for they are the organs by which the charcoal of the food is burnt by slow combustion. The starch of the food, being converted into chyle, is conveyed in a soluble state to the thoracic duct, and thence to the lungs, in venous blood of a dark colour, and loaded with charcoal. This coming in contact with the oxygen of the air, the charcoal undergoes combustion just as coals do in an ordinary fire, and, like them, throws out heat to all parts of the system. Practically, therefore, starch may be considered as the coals, or fuel, of the human system. Hence, with oils, fats, sugar, &c., it is called a *heat-giver*, a quality, of course, of the highest importance in animal life.

Sugar.—This is directly produced from a large number of plants—as in the fruit when ripe—but especially by the sugar-cane, maple, palm, beet-root, &c., all of which are of high value in commerce, and for food uses. Sugar—at least that obtained from the sources we have named last, and generally termed *cane-sugar*—is composed of twelve parts of carbon, and nine each of hydrogen and oxygen ; and hence it differs from starch, by containing one proportion less of each of the latter elements. *Grape-sugar*, as produced from the grape, has a constitution of twelve proportions each of carbon, hydrogen, and oxygen. It may be procured even from linen rags, by acting on them for some time with sulphuric acid. Starch, again, may be converted into grape-sugar by sulphuric acid diluted, by the action of which it is first changed into *dextrine*, and then into the sugar last named.

In the operation of malting, the starch is similarly converted into dextrine and grape-sugar. This is caused by allowing germination to proceed so far as to first produce a substance called *diastase*, which then converts all the starch into sugar. Hence the method by which barley is prepared for the use of the brewer and distiller, by the maltster.

Gum is a substance widely distributed, and produced by numerous plants or trees. In our own country, the plum and cherry tree exude, frequently, much gum from the stem. Gum-arabic, the purest form of gum proper, is distinguished from gum-resins by being soluble in water, but not in spirit ; whilst the gum-resins are insoluble in water, but soluble in spirit, turpentine, &c. The chemical constitution of gum is midway between that of cane and grape-sugar.

Lignin is the basis of wood, and forms the solid part of the leaves and stems of plants. It is fibrous in its form, and is familiarly illustrated in cotton, linen, &c. With starch and gum it forms the chief portion or mass of all parts of living plants ; and, as such, is of great importance as a proximate element.

Oil and Fats may be last noticed. These are obtained chiefly from being secreted in seeds, pulp of fruit, the exterior of leaves and stems as wax, and rarely in the root. As an object of commerce, they are highly valuable to the farmer ; the refuse of seeds, as that of linseed, cotton, mustard, &c., affords an excellent means of fattening cattle, in the form of the well-known oil cake, afforded during the pressure or stamping of the seed to extract the oil.

The preceding are the chief proximate principles of the plant. It will, of course, be seen that we have entirely omitted such as contain nitrogen. The chief of these are the *gluten* of wheat, and the *legumin* of peas and beans.

The gluten of wheat remains in the bag spoken of, to be used for the extraction of starch from flour, when we just described the sources of starch. It is a glue-like substance, and the source of flesh, &c., to those entirely living on bread as an article of diet. Owing to the

power which gluten and legumin share of producing flesh in animals fed on them, they, with certain proximate animal principles, now to be described, are called *flesh-formers;* for, on the presence of some or all of these, the power of producing and sustaining the flesh, &c., of the animal form depends essentially.

A remarkable similarity exists in the proximate principles of plants and animals. Thus vegetable albumen, and that formed by animals, as in the white of an egg, are nearly alike in constitution, each containing about 53 to 55 parts of carbon, 7 of hydrogen, and 22 of oxygen, besides sulphur and phosphorus, present in minute proportions in the animal form. Similarly vegetable fibrin is composed of almost the same proportion of constituents as that of animals, each containing from 53 to 54 per cent. of carbon, 7 of hydrogen, rather over $15\frac{1}{2}$ of nitrogen, and about 22 of oxygen, besides sulphur and phosphorus, in the animal fibrin, as in the albumen.

The nutritive value of different plants and their products will, of course, depend on the proportions in which they contain heat-giving and flesh-forming substances; and the following table will not only be interesting, but exceedingly useful for the consideration of the farmer, because it points out the special qualities in this respect attached to each of the crops he grows. The results arrived at, by chemical analysis, are as follows, the quantities being given per cent.:—

	Heat-giving.	Flesh-forming.
Wheat	60	13
Barley	48	13
Oats	40	17
Rye	51	$13\frac{1}{2}$
Buckwheat	50	$8\frac{1}{2}$
Rice	74	$6\frac{1}{3}$
Millet	70	$8\frac{1}{2}$
Peas	37	$23\frac{1}{2}$
Beans	36	24
Potatoes	$15\frac{1}{2}$	$1\frac{1}{2}$
Parsneps	6	$1\frac{1}{4}$
Carrots	6	$\frac{2}{3}$
Turnips	4	$1\frac{1}{10}$
Cabbages	$3\frac{2}{3}$	$1\frac{3}{4}$

Now, in the above table, not only is a guide afforded in respect to human food, but also for feeding cattle. It is evident that the last four articles of diet, either for man or beast, convey but little nourishment. In the table, the difference between the total of the two sets of figures and 100, shows the amount of water in each vegetable product. Thus turnips and cabbages contain nearly 95 per cent. of water; carrots and parsneps from 92 to 93 per cent.; and potatoes nearly 83 per cent. of water. All this liquid has to be carried or carted, and affords not the least nourishment. It is, of course, otherwise valuable as affording the water necessary for the formation of the blood; but that is generally easily obtained from a pond or stream. On the other hand, such crops take little of solid matter, mineral or vegetable, from the field; and they are generally grown on soil from which more valuable crops have been raised, and have exhausted the ground.

The proximate elements in animals are, as we have previously stated, in some cases, analogous to those of plants; for they both possess albumen, caseine, and fibrine.

Albumen of animals derives its name from the Latin *Albus* (white), and is so known in the white of an egg. It forms an important part of the blood in the serum of that fluid, produced when blood, obtained from the body, has been allowed to stand for some time. Heated to a temperature of about 160°, it coagulates, or becomes solid—a circumstance familiarly known in the operation of boiling an egg. The same occurs in roasting and boiling meat; for its albumen solidifies, and gives a solidity to the whole mass, that, in the uncooked form, it did not possess. Albumen contains the following constituents: namely—

Carbon	53·5
Hydrogen	7·0
Nitrogen	15·5
Oxygen	22·0
Phosphorus with lime, as the phosphate	0·4
Sulphur	1·6
	100·0

Fibrine takes its name from the fibrous character it possesses. It may be obtained by draining away the liquid portion of the blood in a porous bag, when it will be left as a clotted mass; or by whipping up the red portion of the blood with twigs, and washing it with water and ether, when it will be obtained in the form of extremely fine fibres. Its chemical constitution resembles that of albumen, and is—

Carbon	52·7
Hydrogen	6·9
Nitrogen	15·4
Oxygen	23·5
Phosphorus	·3
Sulphur	1·2
	100·0

Caseine.—To the farmer, this proximate animal principle is of the highest importance, for it is that which affords him cheese. It is well known that, if a little rennet be added to milk, it speedily divides into two parts—one fluid called *whey*, and the other solid termed *curds*. The latter is an impure form of caseine, being mixed with the fatty matter of the milk. The *Legumine* of vegetables, already repeatedly noticed in connection with leguminous seeds, as peas and beans, is identical with the caseine produced by animals. In cheese, as ordinarily made, a large amount of fatty matter exists besides the caseine; and the proportion and quality of the fat determines the richness of the cheese. As the fat oxidises, it becomes rancid, and butyric acid with ammonia are set free; hence the peculiar flavour of different cheeses, and the variation of it in the same

cheese, as the latter grows older. The chemical constitution of caseine is—

Carbon	53·83
Hydrogen	7·15
Nitrogen	15·65
Oxygen	22·33
Sulphur	1·04
	100·00

In looking over each of the analyses of the proximate elements of animals already given, it will be seen that they differ very slightly; and it is a singular fact, in chemistry, that we frequently meet with substances having precisely the same constitution, but that have different properties, whether chemical or physical.

Gelatine and *Chondrine* much resemble each other, but have their differences. Gelatine is readily obtained from the skins of animals by boiling; hence the manufacture of glue, size, &c. Leather is produced by converting the skin of animals into a solid mass by the action of tannin, obtained from oak-bark and other sources. The purest form of gelatine is that known as isinglass, obtained from the bladder of various species of the sturgeon. Gelatine readily produces a jelly as it cools from a hot solution, as seen in calf's foot and other animal jellies. In this it differs from *chondrine*, which does not so turn into a jelly. Their chemical constitution much resembles those already mentioned; but chondrine possesses less nitrogen than gelatine. It is obtained by boiling the cartilages of the bone; and is an abundant product in bone-boiling, being taken from the bones before they are converted into various forms for use as manure on the farm. Pieces of skin and cartilage often enter into the composition of artificial manures, for which they are properly available, containing, as they do, carbon, hydrogen, oxygen, and nitrogen, in proportions not greatly differing from those of albumen, &c.

The preceding are the most important of the proximate principles of animal nature, to which may be added horns, hair, the matter of the blood, kreatine, globuline, &c. But these are of most interest in immediate connection with animal rather than agricultural chemistry; and hence their mention alone will be sufficient.

Urea, and the products of urine.—These are of great importance to the farmer, as obtained from all animals; but especially in regard to guano, which is chiefly composed of uric acid united with ammonia.

Urea, whilst similarly constituted to albumen, caseine, &c., greatly differs in one respect; for it contains about 47 per cent. of nitrogen; and hence is so valuable in the urine of man, for fertilising the land. On the other hand, whilst albumen, &c., contain so large an amount of carbon, as shown by the preceding analyses—50 per cent. and upwards—urea contains not more than 20 per cent. In fact, the relative proportions of the two elements, nitrogen and carbon, are inverted as regards urea. It also contains a larger proportion of oxygen; but about the same proportion of hydrogen as albumen, &c.

In uric acid, the product of urine already mentioned, the farmer has a considerable source of nitrogen, it being present to the extent of 32 per cent.; hence the great value of guano as a manure. Uric acid is a product of human urine; but an analogous acid, the *Hippuric,* is obtained from all gramnivorous or grass-eating animals. It contains a much less proportion of nitrogen, the latter not exceeding 8 per cent.

In human urine, the proportion of urea is about thirty parts out of every thousand by weight. But besides the urea, certain salts of ammonia are present, which add to the quantity of nitrogen available from that source. As the urine putrefies, the urea becomes converted into ammonia, which causes the peculiar pungent smell well known under such circumstances.

Animal Oils and Fats.—These are the product of the starch, fat, &c., taken as food; hence the use of oil-cake in fattening animals. Practically, except in the form of a fat beast, they are of little interest to the farmer; and we shall, therefore, pass them over by stating that they are destitute of nitrogen.

Last in the order of animal principles and products, we may mention a valuable addition to the stock of farm manures. Bone consists of earthy matter held together by membrane. According to some analyses, it consists of—

	Man.	Ox.
Animal matter	33·30	33·30
Phosphate of lime, and a trace of fluoride of calcium	53·04	57·35
Carbonate of lime, or chalk	11·30	3·85
Phosphate of magnesia	1·16	2·05
Soda, and chloride of sodium, or common salt	1·20	3·45
	100·00	100·00

It will now be perceived how bones are capable of supplying so much phosphorus in the form of a union of phosphoric acid with lime. This, by the above analysis, is shown to be present to the extent of, on an average, 55 per cent.; and it is this that is the source of the "superphosphate," now so much in vogue as a manure.

We have thus described all the leading ultimate and proximate principles, or elements of plants and animals; the ultimate showing what the soil has to provide for the plant and the animal, and the proximate, substances into which the vitality of the plant and animal converts them. The study of the proximate principles teaches the farmer what he does on his farm; whilst that of the ultimate elements shows him the material that he either has or must have. It will be thus perceived, as already urged, that the agriculturist, whether he knows it or not, is a chemist working on a large scale, with an enormous laboratory, converting dead inanimate soil into life, power, and intellect.

Proximate Principles of the Soil.—There are certain proximate principles in the soil that are analogous to those of the organised forms of plant and animal life; but the discussion of these will be made more fitly in a subsequent part of this section, when we consider the peculiarities of

soils, and the effects of manure, with the treatment of them. Similar rules for the chemical analysis of soils, qualitative and quantitative, may also be deferred.

Physical Conditions.

Scarcely less important than the geological and chemical conditions of agriculture, are those which deal with the forces of heat, light, &c., and the mechanical circumstances that affect the condition of land under culture.

Under the head of Physical Conditions we include the effects of heat, light, electricity, and the various mechanical conditions of friability, porosity, &c., with the effects of climate, and meteorological phenomena generally ; all of which have the highest influence, not only in determining the fertility of the soil, but also of necessitating the choice of crops that can be grown to the best advantage.

Taking first, in order, the influence of *heat*, and *temperature*, it is well known that all plant-products, and, to a lesser degree, animals, are local within certain zones, exterior to which, if they are afforded, their production is, to a certain extent, non-natural.

In our own climate, for example, wheat cannot be profitably cultivated in the north of Scotland, except under very exceptional circumstances, chiefly because the yearly average temperature falls too low to permit of its properly ripening. For similar reasons there is a limit in the south of Europe, beyond which, whilst maize or Indian corn and rice may be abundantly grown, wheat ceases to be a profitable crop, excess of annual temperature being the cause in this latter case. The mean annual temperature of the wheat-growing countries of Europe, extending from Yorkshire, in England, southward in latitude, as far as northern Italy, ranges from about 50° to 55° Fah., with a latitude of about 45° to 55° N ; and it is within this limit, in respect to Russia, Austria, Prussia, Germany generally, Lombardy, France, England, &c., that most of the bread-corn of Europe is produced.

South of this limit we have semi-tropical productions afforded, as rice, maize, cotton, the date, oranges, &c., &c.—crops that require not only a high average temperature annually, but also a high temperature at the season of ripening.

It must be borne in mind, however, that the annual temperature of any locality depends on its elevation above the sea-level ; and thus at many portions of the earth's surface, whilst at the lowest, or sea-level, a great amount of heat is felt, a greater elevation is attended with a gradual decrease of temperature ; therefore, even in tropical climates, it is possible, and even usual, to grow the crops common in more temperate regions. Thus, far south of Europe, in many parts of Asia and America, the elevation of the mountains is such, that under the burning rays of the tropical sun, snow may be seen on the tops of many of them. Our Indian possessions are thus characterised by a variety of climates, that permit them to produce every plant, from the saxifrage of the arctic regions to the rich fruit of those produced in the tropics ; hence, not only latitude, but elevation above the sea-level is also a consideration of the highest importance in regard to the temperature of any country or special locality.

Restricting our remarks, however, after this general statement, to the circumstances of these islands, in respect to heat, it may be observed, as a rule, that elevation less affects the farmer's operations than the chemical and mechanical conditions of the soil. In all cases of much or important elevation above the sea-level in Great Britain and Ireland, the difficulty of growing crops does not arise from the height, but rather from the absence of soil in such localities. Familiar examples of this fact are found in Cumberland, Westmoreland, and other northern counties, where, whilst the valleys are filled with rich alluvial matter, the ridges and tops of the hills are almost bare of soil ; and, consequently, are destitute of vegetation.

The colour of the soil greatly determines its temperature. Those soils that are black absorb heat rapidly ; but also rapidly part with it ; for according to the laws of heat, a substance that readily absorbs that force as readily radiates it. On the other hand, a white soil, such as chalk, has little power of absorbing heat ; but, having once absorbed it, the radiating power being slight, the higher temperature is much longer retained than occurs with black soils. The surface soil of Kent, and adjacent counties, is, perhaps, scientifically considered, the best for corn-growing, and other purposes, of any in the kingdom ; for, being of a light colour, comparatively speaking, its absorbing, radiating, and reflecting powers are all in what may be termed a happy medium.

The function or office of heat is that of producing and developing those chemical changes that precede and accompany germination. Some familiar illustrations will point out what is here meant. For example, an animal or a plant, or their products, will undergo no chemical changes whatever if kept at a temperature below 32°, or freezing-point : hence, on the Alps, bodies that have been found years ago are kept for an indefinite time without putrefaction ; and similarly in this country, meat may be kept sweet for weeks if not allowed to attain a higher temperature than about 40°.

But as the temperature of an animal or a plant increases, there arises a series of chemical changes, that, if acting on organised matter destitute of vitality, causes putrefaction ; or if on a vital organism, as a seed, produces in it the first step towards growth and reproduction. Thus the seed sown in spring, or autumn preceding it, gradually becomes affected by heat ; and one of the first steps is the conversion of its starch into sugar—the first food of the incipient plant that is soluble and fit for its sustenance. The malting-floor illustrates our meaning. There germination is commenced by artificially heating the barley ; the seed is thus stimulated to put forth the exercise of its vital power, and consequently begins to grow.

Hence the difficulty of growing crops on what are called "cold" soils. They do not absorb and retain sufficient heat to cause the first germination of the seed in some cases, and in others to produce those chemical changes in the soil essential to the nutrition of the plant when formed and rising out of the earth. But in such cases it is not always that a want of absorbing power is the sole cause. It frequently happens that either a large quantity of undrained matter remains on the land, or that the evaporation from its surface is so rapid that the plant is all but frozen to death. Instances of these two kinds of circumstances may be named. In our own country, stiff clay, marsh, and reedy surfaces present the conditions arising from want of drainage, in which the water conducts away from the seed or plant the heat necessary for its development. In respect to the other case—that of rapid evaporation—we may mention the Sahara desert of Africa; where, although in the daytime the temperature in the sun rises to 150°, almost equal to boil an egg or set its white, yet, at night, it frequently falls to 32°, or freezing-point, owing to the rapid evaporation of moisture, and the consequently rapid radiation of heat. The same occurs in most tropical climates; and even in England we have, on certain occasions, observed a temperature in *the shade*, at daytime, in July, of 84°, whilst, under a clear sky, the thermometer has fallen to 32° at three on the next morning.

Some very interesting discoveries were made by Dr. Tyndal, of the Royal Institution, London, on the effects of moisture in the air preventing such extreme changes in temperature; and hence there is a limit to the otherwise universal law, that a damp climate is a cold one. For example, if at some distance above the surface of the ground, a certain amount of moisture be present, rapid evaporation is prevented, and consequent loss of temperature or cold obviated. This is familiarly known as an effect of cloud, for no dew "falls" on a cloudy night; and, consequently, the temperature of the earth falls but little. For precisely similar reasons, it has been customary, for ages, to protect delicate plants at night by a thin coating of straw or matting, which prevents, at the same time, the evaporation of moisture, the radiation of heat, and, consequently, a fall of temperature. It must be borne in mind that, just as there is an animal heat—averaging in man about 90°, or a little higher—so plants that are growing have a higher temperature than would be simply existing in the dead materials of which they are composed. They have, in fact, a vital heat of their own; and if this be lessened by any of the causes already mentioned, or others still to be noticed, they are chilled, and, possibly, undergo just such affections, or their analogues, which, under similar circumstances, act on animals. When we deal with the botanical condition of agriculture, many of our readers will be, perhaps, surprised to find the close analogy or resemblance that subsists between the plant and animal. Plants eat, drink, breath, digest, secrete, excrete, &c., &c., just as animals do; and, in some cases, by similarly constituted organs. Nay, more—they have even sensation, as seen in the common sensitive plant which closes its leaves on being touched, or many plants that shut up their flowers at sunset, or turn them to the sun when he is shining.

It will thus be seen that many of the laws of heat affect the farmer's operations. So much so, indeed, that the best geologically or chemically constituted soil may become utterly useless for the growth of its suitable crop, if circumstances of temperature occur that are inconsistent with its requirements. Of all living creatures, man alone can make himself independent of temperature. He may be placed in an oven that would cook meat to perfection (say at a temperature of 350°); or he may be kept alive for years in a climate that will break every tree to pieces with the frost, freeze mercury, render even wine nearly solid—yet he comes out of either ordeal safe and unscathed. But with plants and the lower animals the case is widely different. Destitute of intelligence, neither can sufficiently provide for the exigencies which each extreme imposes; and hence it becomes one of the highest branches of farming science, to intelligently study such conditions as we have briefly described, and to apply them in the operation of producing crops or breeding stock.

Light.—Until comparatively recent years, the influence of light, accompanied by heat, was little attended to, especially in regard to horticulture; but its importance will be made manifest by the following considerations. And first it may be noticed, that, on the shaded side of a hedge, and at some distance from it, neither grass nor corn will grow well. At one time, this was accounted for by the opinion that the free access of air was prevented; but from extended observation in all parts of the country, we cannot come to any other conclusion, than that it is the loss or prevention of access of light that is the general cause. In a forest or thickly-wooded country, precisely the same thing occurs; for there scarcely the scantiest herbage will grow beneath the trees—an effect due to the prevention of light, although occasionally and fancifully accounted for by the supposed resinous or other droppings of trees. But if this be the case, how is it that inferior branches of the same trees, crowded together in a wood, are destitute, comparatively, of foliage, whilst, where each branch has equal access to light, the foliage is abundant?

Again, whilst at the first rise of every leaf either above ground or from a bud, the foliage is of a light yellowish-green colour, yet, on being exposed to light, such become of a deep green, deepening, in fact, from spring to autumn, when decay brings another and destructive change. Sir John Herschel published, some years ago, in the *Philosophical Transactions of the Royal Society*, the results of exceedingly interesting experiments that he had made on the colouring matter of leaves. He showed, in fact, that just as the photographer produces an image on the sensitive surface in his camera, converting a transparent surface into one presenting every variety of light and shade, by the agency

of the solar rays; so the sun, acting on the juices of plants, has precisely similar effects in causing their colour, and, consequently, those of leaves and flowers.

A familiar method of the market-gardener, however, will bring more fully home to the minds of our agricultural readers, the influence of light on vegetation, and the colours of plants generally—it is that of blanching, as pursued with celery, endive, lettuces, &c. The outside leaves of each are tied over, so as to enclose those within; and these, protected from the action of the light, retain the white colour which is natural to them in the absence of that agent. A stray onion or a potato in the out-house of the farm, presents exactly the same appearance, if either have budded and grown in the dark.

But not only is the influence of light of a general character; it has also special action in relation to its own colour. The rays of the clear-shining sun are white; but if these be allowed to pass through a triangular piece of glass, as a prism, or even a chandelier ornament, the white ray becomes split up into three primary colours—red, yellow, and blue, by the overlapping of which, at certain portions, green, orange, &c., are also perceived. Now, by experiments that cannot be disproved in their results, it has been found that the *red* rays are those most accompanied by *heat;* the *yellow*, those most associated with *light;* and that in the *blue* resides the *chemical power.* For the sake of distinction, these sets of rays have been termed—those affording heat, the *calorific;* those of light, the *luminous;* and those having chemical action are termed the *actinic.*

Now, strange as it may appear at first sight, these individual sets of rays have as much influence on the farmer's success, as have all the ploughing, manuring, and other operations that he pursues. In the first place, the red and yellow rays are essential to convey heat to the ground. When a seed germinates, it requires to be without light, but needs heat; and as the calorific rays strike the ground they communicate that heat, which, as we have already pointed out at p. 365, *ante*, is essential to those first chemical changes by which vitality is induced in the seed. When, however, the seed has sent forth its first leaf or leaves above ground, then the yellow rays afford both light and heat; but the blue or actinic rays are the most stimulant of further growth and production of colour in the leaf, &c. Thus we have the philosophy of the common complaint in our climate, of "want of sun;" whilst, in tropical climates, we notice the effect of its abundance, in the rich flavour of the fruits, and the equally rich colour of the flowers.

A very simple experiment will bring the subject more plainly before our practical readers. If three equally healthy and similarly grown patches of cress be covered over with a red, yellow, and blue glass, and exposed to light for a week or so, it will be found that the plants under the red rays will be pale and sickly, and but slightly advanced; those under the yellow will not be much better; whilst under the blue or green glass the cress will have thrived well. It is for this reason that it has become a common practice, in building green and forcing-houses, to use glass tinted of a blue or greenish hue; and it has been found that, in practice, the growth of the plants is greatly influenced and benefited thereby.

From these facts we may also draw an argument in favour of thin sowing, and transplanting. If a quantity of seeds be allowed to grow in a mass together, not only do they abstract so much food from the soil as to starve each other; but as they rise they obstruct the passage of light, which, as we have seen, is so essential to plant-growth. In this we see, also, how many circumstances must be taken into account in advising the farmer in respect to the application of scientific principles. We first tell him to mind the chemical condition of his soil, and to provide its proper food; but if we neglect to advise equally about those conditions of heat, light, &c., that have been or are to be expounded, we only half do our business—nay, under some circumstances, fail altogether to do that duty which he has a right to expect at our hands.

We should have to go too far into the laws of animal physiology were we to point out the influence of light on the growth of animals, such as form the live stock of the farm. But briefly we may remark as follows:—

It is well known that, by enclosing an animal or a bird in a dark place, we take away a certain amount of stimulus to nervous and muscular action. Thus a constant state of rest is imposed, which is most favourable for fattening. Their exposure to light, on the other hand, stimulates to exercise, and this opposes the production of fat, but promotes that of muscle and flesh. Even humanity is sensible of these two opposite conditions and their results; and the usual effects of a "dull day" are too familiarly known, in this climate, to require us to do more than cite them as an additional confirmation of the statements here made.

The practical conclusion to be drawn from what has been stated, will require detailed consideration when we enter on the question of practical farming. But in respect to heat and light, as already discussed, it is evident, that every means which can ensure the abundant access of both to the plant, and the adoption of every method that shall tend to remove causes of their absence, must be secured. Amongst such are drainage, to remove excess of moisture both as water and vapour; low hedges; removal of overhanging trees; thin sowing; transplanting; &c. In spade husbandry, and market-gardening, attention to these particulars has already produced the best results; especially, for example, near London, where the annual income obtained from an acre of ground, is frequently much larger than would buy the freehold of an acre but little further north of the metropolis.

Electricity, as one of the physical conditions of agriculture, is of far too undetermined a nature to permit of our discussing it. That it has an influence equal to that of heat and light,

separately or collectively, is very probable, for we know that the three forces are invariably present together. But we cannot, in the present state of electrical science, offer advice of the slightest practical value in regard to agricultural operations, so far as such are connected with the germination and growth of plants.

Only one point worthy of notice can be suggested—it is that of protecting farm-buildings, hay-stacks, &c., by means of lightning-conductors. This may be done in the simplest manner, as follows:—An iron rod, about half an inch thick, and *six* feet longer than the height above ground of the object to be protected, should have each end roughly pointed by means of a file. It should then be fastened upright to the building or stack, so that three feet of it extend *above* the roof or other highest part, whilst the remaining three feet are inserted into wet ground. Such a rod would cost but a very small sum, and would afford certain protection against lightning, the loss by which is never effectually covered by ordinary insurance. Independent of this, a farm, generally isolated, becomes a common object of destruction by lightning, involving not only the loss of insurable property, but very frequently of life. The loss of time in restoring buildings destroyed by lightning, and consequent inconvenience and pecuniary loss in the farm, is an additional reason for the adoption of the safeguard here suggested.

Another series of physical conditions relating to agriculture is found in the porosity, friability, retentive power, and allied circumstances of the soil. These, however, are in part connected with considerations of a geological character; and have been already noticed, generally, in the preceding pages. They are, moreover, subjects specially to be dealt with in the practical operations of the farm; especially that of ploughing, to which separate considerations must be devoted. Generally it may be stated, that the finer the individual particles of the soil, the closer they will adhere together with mixture and pressure; hence the stiff and retentive character of clay soils, alleviated by the admixture of sand, lime, and other substances. The subject is evidently one that we must defer considering until we have examined many other matters on which it is, more or less, dependent. Thus manuring, ploughing, frost, &c., all modify the mechanical condition of the soil, and so prepare it for the reception of the seed at sowing-time.

Here we may notice, that bad as the character is, in the farmer's eye, of mice, moles, insects, worms, &c., they all have a tendency to improve the mechanical condition of land, however they may exercise an evil influence in other directions. Some most ridiculous and serious errors, in their results, have thus been committed in destroying nature's scavengers. Sparrow clubs are amongst those foolish institutions that recoil on the heads of their originators. Except in special cases (as, for example, a flight of locusts, and even that has its advantages), the powers of nature equally balance each other. Man shoots game, and so prevents the entire destruction of his crops; but if he exceed proper bounds and exterminates them, finds that he commits an error; for all birds largely live on the grubs and larvæ of insects, which, if allowed to remain in excess on the land, would destroy its fertility. Still, if the worm, moles, and other vermin, were not permitted to exist, a most efficient means of subsoil ploughing by natural means would be lost; for all such creatures tend to open the soil, and, consequently, to drain. The tracks such animals form, also leave channels, through which the radicles, or little roots, of plants find their way in search of food and moisture.

It is a common opinion, that the best harvests generally occur after a preceding severe frosty winter; and science at once points out, that the effect of frost on the soil is that of breaking it open, and thus forming channels, minute though they be, for drainage, and also permitting the passage of the radicles of the plant, as just named. Now, the more extended their radicles, the greater the amount of food collected by each root, all other circumstances being equal. But, beyond that, an extension of the root thus adds to the stability of the plant, by giving it a firm hold in the ground; and also by the abundant supply of mineral, giving a better back-bone of silica to the straw. Hence, amongst circumstances of a physico-mechanical nature, frost is one of the most important. We must add, that a fall of snow attending frost, has the double advantage of preventing loss of heat, and the destruction of the root or incipient plant; whilst, near towns, it also brings down a minute portion of sulphate of ammonia, the results of the products of adjacent coal-combustion.

Generally, the effect of a heavy shower of rain is to beat down the ground, and close its surface pores; but against this evil nature provides a remedy; for, so soon as the sun regains its power after the storm, as the soil dries up it splits into cracks, opening ready to receive the next welcome shower, and to convey its enlivening influence to the thirsty root. Thus, wherever we look in nature, we find an almost exact counterbalance of one influence by another, all tending to the best results, whether they cannot be controlled by man, or are subjects in which the exercise of his intelligence is requisite.

This leads us next to the consideration of a most important influential element in the farmer's pursuits—we refer to climate, and its meteorological characters.

Without in any way assenting to the opinions, or following the practice, of those who unhesitatingly affirm that the meteorological conditions of any locality may be, as a rule, safely predicated, still it must be admitted that great progress has been made, of late years, in that direction; and meteorology, as a branch, is of equal value as a study, and of practical application, to the farmer, as it is to the navigator.

Generally speaking, both are what is called weather-wise; by which we mean, that long experience in the open air, obtained by watching natural indications, leads to a greater or less

amount of certainty in predicting weather, that may immediately or shortly occur, and sufficient to guide the sailor and agriculturist in a variety of matters of importance to both.

Science affords a valuable guide to the attainment of a probable state of the weather in the barometer and thermometer, the variations of which are dependent, respectively, on the increased or decreased pressure of the air, and on alternations of temperature. If the mercury in the barometer fall, it is usually to be considered a sign of coming wet; and, if that fall be rapid, heavy storms of wind, hail, and rain or snow may be expected, according to the season of the year. Independently of the barometer, the thermometer affords no indications of the weather; for in the course of the same day, and amongst the finest of any season, the variation of temperature is often considerable. It may be borne in mind, however, as a general rule, that the thermometer rises as the barometer falls, so far as our climate is concerned, but this is chiefly due to the change of wind, as, for example, from a north to a south wind.

But the thermometer may be made, with the barometer, very indicative of probable weather, provided an average be struck between the daily variation and the average temperature for any month at any locality. Taking, for example, the neighbourhood of London, and a few miles round it, meteorologists have found, by comparison of observations for many years, that a mean temperature may be arrived at for each month; that is, a number between the highest and lowest temperatures has been arrived at, which may be considered as the mean temperatures of the month. In London, these temperatures are about—in

	Fah.
January	37°
February	39°
March	41°
April	46°
May	53°
June	59°
July	62°
August	61°
September	57°
October	50°
November	43°
December	39°

These are the mean temperatures for the month, taken between 8 and 9 o'clock in the morning; the thermometer, of course, being shaded from the rays of the sun, raised six feet above ground, and *not* blown on by the wind.

If now, on any day, between 8 and 9 in the morning, the thermometer be higher than the preceding average for any month, it indicates the approach of a south, south-westerly, or westerly wind. But if the thermometer indicate a lower temperature, then a wind from a northerly direction may be expected. Under such circumstances, the southerly winds will, probably, bring rain, and the northerly winds dry weather. Because our hot winds in these islands come from south and west, the temperature rises under such circumstances; and as our northerly winds bring cold air, therefore the thermometer falls.

Similarly, the barometer is at the same time affected, *not* by the action of heat on the mercury it contains, as is the case of the thermometer, but because hot air being lighter than cold, weighs less, and consequently presses with less force on the mercury of the barometer. On the other hand, the northerly wind being colder, condenses the air, making it weigh more for the same bulk, and so pressing on the mercury in barometers with greater weight, causes it to rise in the glass.

From these facts—for they are not theories—the farmer may gather, that if the thermometer rises, and the barometer falls at the same time, a change for wet is almost sure to follow. And, on the other hand, if the thermometer fall and the barometer rise, cold and dry wind intermingled with showers, if from the south or west, may be expected. On an average, in our islands, except in mountainous districts, these indications may be generally depended on.

Sudden rises and falls of either temperature or pressure seldom last long, and are generally caused by local disturbances of the air, acting like an eddy or whirlpool in water. A sudden fall of the barometer, however, to the extent of a quarter of an inch or more, is almost a sure forerunner of a storm. In harvest-time, a barometer may thus be of the greatest service to the farmer; and in the hay season plenty of warning would be given to cover the stacks in process of erection, so as to prevent them from being wetted—a most common cause of their being set on fire by spontaneous combustion. On one occasion we saw six ricks catch fire, that in each case had been caused by stacking the grass, and allowing it, during the operation, to become wet by heavy showers. No sign of heating occurred for two or three months; but during a very hot week, the whole caught fire from this cause.

The use of the barometer at sea has now become universal; and its indications are considered as of equal value, in respect to weather, as the compass is in steering. A certain fall in the barometer would immediately be followed by orders to furl sail, and to make every precaution for a coming storm. As there is no circumstance on land, except in mountainous districts, that is not common on the sea, the farmer ought in the same way to use his barometer as a good guide, which, if it have any error, is sure to be on the side of suggesting wise precautions.

Many natural occurrences, arising from scientific causes, may also be used as a guide to judge of probable weather. As the air gets drier it abstracts moisture from all surrounding objects. Thus, a rope drawn tight between two posts will become slack in dry weather, because of the removal of moisture from its pores; but as moist air and wet weather come on, the rope will again tighten, owing to its absorbing moisture from the surrounding air. It is on this principle that the hygroscope is constructed. A simple form

of it is that of stretching a hair by passing it over a little pulley, and attaching one end of it to a piece of wood or a nail, whilst the other is fastened to a little weight. A needle stuck in the pulley serves as an index. Thus, if the weather be getting drier or damper, the extension or contraction of the hair will indicate the coming change, and move the pulley and index right or left, according to the side on which the little weight is hung. Seaweed, again, from containing a salt that abstracts moisture from the air, gets soft and wet in moist weather, but crisp and dry in dry weather. It is another and very simple form of hygroscope, or moisture-shower. Steam and smoke also indicate moisture in the air, by descending bulkily in moist weather, for then the air is so charged with vapour that it can take up no more. Thus, in moist weather, the steam of the locomotive spreads largely, and remains suspended as a cloud; whilst in dry weather, the air, being deficient of vapour, rapidly absorbs it, and it, consequently, quickly disappears from sight.

The late Admiral Fitzroy, so well known for his study of meteorological phenomena, and devotion to which caused his sudden and lamented death, remarks as follows: and most of our readers will agree with us in saying, that the signs he mentions are almost universally to be depended on.

"A few of the more marked signs of the weather, useful alike to seaman, *farmer*, and *gardener*, are the following:—

"Whether clear or cloudy, a rosy sky at sunset presages fine weather; an Indian-red tint, rain; a red sky in the morning, bad weather or much wind, perhaps rain; a grey sky in the morning, fine weather; a 'high dawn' wind, and a 'low dawn,' fair weather. A 'high dawn' is when the first indications of daylight are seen above a bank of clouds. A 'low dawn' is when the day breaks on or near the horizon, the first streak of light being very low down.

"Soft-looking, or delicate clouds, foretel fine weather, with moderate or light breezes; but hard-edged, oily-looking clouds, wind. A dark, gloomy, blue sky, is windy; but a light, bright-blue sky, indicates fine weather. Generally, the softer clouds look, the less wind, but, perhaps, more rain may be expected; and the harder, more 'greasy,' rolled, tufted, or ragged, the stronger the coming wind will prove. Also, a bright-yellow sky at sunset, presages wind; a pale-yellow, wet; and a greenish, sickly-looking colour, wind and rain. Thus, by the prevalence of red, yellow, or other tints, the coming weather may be foretold very nearly—indeed, if aided by instruments, almost exactly." (We may here parenthetically add, that this is owing to the varying amount of moisture in the air, which causes the different colours of the clouds.)

"Small inky-looking clouds foretel rain; light scuddy clouds, driving across heavy masses, show wind and rain; but, if alone, may indicate wind only.

"High upper clouds crossing the sun, moon, or stars, in a different direction from that of the lower clouds or the wind, as felt on the earth, foretel a change of wind towards their direction.

"After fine, clear weather, the first signs in the sky of a coming change are usually light streaks, curls, wisps, or mottled patches of white distant clouds, which increase, and are followed by an overcasting of murky vapour, that grows into cloudiness. This appearance, more or less oily or watery, as wind or rain will prevail, is an infallible sign.

"Usually, the higher and more distant such clouds seem to be, the more gradual, but *general*, the coming change of weather will prove.

"Light, delicate, quiet tints or colours, with soft undefined forms of clouds, indicate and accompany fine weather; but gaudy or unusual hues, with hard, definitely outlined clouds, foretel rain, and, probably, strong wind.

"Misty clouds, forming or hanging on heights, show wind and rain coming, if they remain, increase, or *descend*. If they rise or disperse, the weather will improve or become fine.

"When sea-birds fly out early, and far to seaward, moderate wind and fair weather may be expected. When they hang about the land, or over it, sometimes flying inland, a strong wind, with stormy weather, may be expected. As many creatures besides birds are affected by the approach of rain or wind, such indications should not be slighted by any observer who wishes to foresee weather, or compare its variations.

"There are other signs of a coming change in the weather, known less generally than may be desirable, and therefore worth notice; such as—when birds of long flight, as rooks, swallows, or others hang about home, and fly up and down low, rain or wind may be expected. Also when animals seek sheltered places, instead of spreading over the usual range; when pigs convey straw to their styes; when smoke from chimneys does not ascend readily or straight upwards during calm, an unfavourable change is probable.

"Dew is an indication of fine weather, so is fog. Neither of these two formations occurs under an overcast sky [see our remarks on this at p. 366, *ante*], or when there is much wind. Occasionally we see fog rolled away as it were by wind, but seldom or never actually formed while it is blowing.

"Remarkable clearness of the atmosphere near the horizon; distant objects, such as hills, *unusually visible;* or raised by refraction, and what is called a "good hearing day," may be mentioned among signs of wet, if not wind, to be expected.

"More than usual twinkling of the stars; indistinctness or apparent multiplication of the moon's horns; haloes; 'wind-dogs'—that is, fragments of the rainbow seen on detached clouds—and the rainbow, are more or less significant of increasing wind, if not approaching rain with or without wind. Remarkable clearness is a bad sign. The 'young moon with the old moon in her arms,' is a sign of bad weather, * * * probably because the air is thin, exceedingly clear, and transparent.

"Near land, in sheltered harbours, in valleys,

or over low ground, there is usually a marked diminution of wind during part of the night, and a dispersion of clouds. At such times, an eye on an overlooking height may see an extended body of vapour below, rendered visible by the cooling action of the night, that *seems* to check the wind.

"It should be remembered, that the state of the air foretels *coming* weather, rather than shows the weather that *is present* (an invaluable fact too often overlooked); also that the longer the time between the signs and the occurrence of the change they foretel, the longer such altered weather will last; and, on the contrary, the less the time between the warning and the change, the shorter will be the continuance of such foretold weather.

"Though the barometer generally falls with a southerly, and rises with a northerly wind, the contrary sometimes occurs; in which cases the southerly wind is usually dry, with fine weather, or the northerly wind is violent, and accompanied by rain, snow, or hail, perhaps with lightning. The north-east wind raises the barometer most; and the south-west wind depresses it most. * * * When the wind appears to veer round in the direction of the sun, fine weather may be expected; but the reverse indicates foul weather.

"Sometimes severe weather from the southward, *not lasting long*, may cause no great fall because followed by a duration of wind from the northward; and, at times, the barometer may fall with northerly winds and fine weather, apparently against these rules, because a continuance of southerly wind is about to follow."

The preceding quotation, coming from an excellent authority, deserves the most careful perusal and attention of the farmer. We may add that, for a period of about thirty-five years, our personal experience in all parts of our islands exactly agrees with what has been said; the only exception being, as already stated, in mountainous districts, where a variety of local causes necessarily modifies the signs of weather. Generally, however, in Great Britain and Ireland all such signs may be implicitly relied on; and, with the barometer, should be considered as an invaluable guide to the agriculturist.

In respect to rain-fall, an important meteorological occurrence, but few remarks can be made. In England, on an average rain, falls, in the course of the year, to an extent that would cover the whole level area of the country to a depth of about thirty-one inches, taken on an average of years. But, for some years past, this average has been somewhat lessened, most probably owing to improved drainage, which has a great tendency in all countries to lessen the rain-fall. At the same time the local fall of rain in this country greatly varies. In Essex and Kent it may be considered as about the average of thirty-one inches annually; but at a hill near Borrowdale, in Cumberland, the mean fall of four years gave 163 inches annually, and it has risen as high as 200 inches in some years—an enormous amount, approaching to the highest registered in tropical regions, and more than double the annual average of the whole of India. Hence the reason that we have excepted the mountainous regions in this country when remarking on its meteorology generally, as affecting the farmer.

In the neighbourhood of all large towns in our islands, the rain falling on the land is to be considered not only as moistening the soil, but also as acting the part of a manure. In such localities, owing to the products of combustion and breathing greatly vitiating the air for humanity, the plant is consequently benefited; for the atmosphere, from this cause, becomes charged with a great amount of ammonia and carbonic acid, two of the chief requirements of plants. These are dissolved by the falling rain, and are carried in a state of solution to the soil, whence they are absorbed and assimilated by the roots of plants. Thus the cause of injury to the animal kingdom becomes a benefit to the vegetable; which, abstracting the poison from such gases for its own food, returns the oxygen (see *ante*, p. 355) to the air again, to be respired by the animal—a beautiful provision of nature, eminently evidencing design.

Owing to the influx of warm moist air on the west coasts of Ireland and Scotland from the Gulf-stream, that there impinges on our island, those districts present a freshness and greenness found in no other part. For example, in 1864 we took a journey through the whole length of England and Scotland, towards the end of autumn. Scarcely a field showed, owing to the drought of the previous summer, anything but the dry brown blade of burnt grass. On arriving, however, on the west coast of Scotland, each field presented the richest hue of green, affording a sight, after a journey of twelve hours, that was truly refreshing. On crossing over to Ireland, precisely the same thing was observed; for the moisture of the air on the west coast had permitted of the growth of grass that, in England, had been completely parched up. For similar reasons, in winter, the west coast of Scotland is preserved from anything like severe frost. Perhaps the most remarkable instance of this kind may be seen in the islands of Bute and Arran, at the mouth of the Clyde, in winter. Seaward, about January, we have noticed the honeysuckle in leaf, and the temperature almost summer-like; whilst five miles inland, behind the Argyll hills, snow laid thick on the ground, not only on the hills but in level patches, and, at the same time, the whole east of England, from London northwards, had ice upwards of ten inches thick.

The position of our islands necessarily is favourable to considerable fall of rain, especially in Ireland, where the average rises considerably higher than in England. On the west coast of Scotland it attains to from thirty-five to forty-five inches, on the average. The reason of this moisture, fog, &c., in our islands is at once apparent. On the east we receive the cold winds of the Russian plains; on the west, the hot moist winds of the Atlantic and the Gulf-stream. The cold east wind meeting with the

warm moist west to south winds, causes the latter to condense, first to form cloud, and next to afford rain. Hence the uncertainty of our climate, as affecting farming operations. The farmers of Cumberland and Westmoreland are practically well acquainted with this circumstance, which, whilst increasing the difficulties of agriculture in those counties, stimulates to the exercise of a high state of farming, as creditable to their intelligence as, despite of all difficulties, it is profitable. In many districts—a few miles south of Carlisle, for example—the farmers so successfully till and breed as to compete with their more southern brethren.

The agricultural value of rain will depend, not only on its quantity, but also on the soil. Thus such soils as those of Kent and adjacent counties can "take" any quantity of rain, which, whilst of the greatest benefit *there*, completely swamps the midland counties, at least the southern portion of them. In 1865, towards the end of November, after the fearful storms that burst on our southern and westerly coast, we had occasion to traverse England and Scotland, from Cornwall to London, and thence to Dumfries, in about thirty-six hours by railway; and certainly, the variety of results from the great rain-fall was astonishing in this journey of between 500 and 600 miles. From Truro to Exeter, the undulatory character of the country had permitted of an almost entire drainage-off of the fallen rain; and from Exeter to London, little sign of excess of water was visible, chiefly due, in this district, to the porous nature of the soil. But north of Watford, for many miles, the light of the moon was reflected by extensive fields of water, that covered the rich grazing lands, more or less, to Rugby, beyond which little sign of flood appeared for the whole distance to Carlisle. Hence, from this illustration, it is evident that the effects of the excessive or ordinary rain-fall, are wonderfully different in reference to farming operations.

A high local temperature also modifies the effect of excessive or ordinary rain-fall. Thus, in tropical regions, an enormous amount of rain —even inches in the day—is not only beneficial to all tilling operations, but even essential, because the evaporation caused by the excessive heat is so great. But even the moderate rain-fall of our islands—say, for example, in the south-east of Scotland, and the Lothians—may exercise a most prejudicial effect on farming operations —a result we have frequently seen in those districts and Perthshire. Hence a large rain-fall can be better borne in the south of England than in any other part of our islands, because of the greater ordinary temperature. The combined influence of temperature and moisture, has rendered, of late years, Cornwall especially, and some parts of Devonshire, a complete garden for early "greens" and salads, great quantities of which are now there grown for the London market.

The insular condition of our country thus presents great advantages to the agriculturist, because, as we have shown, it produces an average rather than an extreme climate. On the continent the reverse is the case, and either drought or flood is common. The British farmer emigrating either to Canada or Australia, enters into entirely different circumstances of temperature and moisture. In South Australia and New Zealand, from the proximity to the sea of the first, and the insular position of the latter, although a larger amount of rain annually falls than with us, still the conditions of farming are similar. But the interior of Australia and Canada, removed from the sea, is characterised by what is called an excessive climate. In Canada the thermometer falls, in winter, to no more than 20° below zero—that is, to 52° below freezing-point; whilst in summer it frequently rises to 100° or 103°. Again, at Sydney, in Australia, occasionally hot winds blow from the north-west that have a temperature of 120° to 130°. These originate from the hot dry interior of that immense island. During their passage they destroy every vestige of vegetable life; wheat-fields and fruit trees are blasted, and every product of the farm is swept away. These winds are also loaded with fine sand, like those produced by the Sahara desert in Africa, and are as harmful to animal as vegetable life. Under such circumstances, if an occasionally large fall of rain did not occur, the land would be absolutely barren. In Egypt, rain is not known; but, as already pointed out, the periodical overflow of the Nile answers precisely the same end in moistening and fertilising the ground (see *ante*, pp. 351, 352.)

We have omitted, however, one source of moisture that is of the greatest value—less, perhaps, in our islands, but of much importance in hot, dry climates—we refer to *dew*.

The cause of dew is easily explained. The hotter air becomes, the more moisture it is capable (with certain limits) of taking up. During the daytime this moisture is held in solution by the air; but at night, if the radiation of heat be great (see *ante*, p. 366), then cold is produced; and the atmosphere losing its power of keeping the moisture in solution, deposits it in the form of dew. Hence, in hot climates, the amount of dew afforded is very great, and frequently, to a degree, compensates for the absence of rain. Even in our own climate, in August, this phenomenon is often noticed in great quantity. But a clear sky is essential to produce dews; for otherwise, as pointed out at p. 366, *ante*, the presence of cloud prevents radiation, and, consequently, the production of dew. In tropical countries, where the air is very clear, and free from cloud during the hot dry season, the deposition of dew is consequently very great.

Although this work is professedly intended for the agriculturists of these islands, it is by no means impossible that it may fall into the hands of intending emigrants, or of those who have already arrived in other lands, where they intend to pursue the practice of agriculture. To them the following table of temperature and rain-fall may, consequently, be of much value. It has been compiled from reliable sources, and presents generally a fair average for each of the

places named for a period of about thirty years. But, in perusing it, the reader must bear in mind what has been said in respect to excess of temperature and rain-fall; in other words, whilst in our climate the variations of each are comparatively moderate throughout the year, in some of the places named the reverse is the case. Thus, at Cayenne, in South America, as much as twenty-one inches of rain have fallen in *one day!*—an amount nearly equal to the whole rain-fall annually for some places.

Table of Mean Annual Rain-fall and Temperature in—

	Inches of Rain-fall.	Mean Temperature. Degrees Fah.
England generally	31	50 to 53
Scotland, West	35 to 45	48 to 49
,, East	22 to 26	47
,, Central	variable	48
Ireland generally	36	50
,, South	40	52
,, Central	31	50
,, North	35	48
France, North	22	50
,, Central	24 to 40	58
,, South	23	60 to 62
Portugal	very variable	61 to 62
Spain	12 to 36	62
Russia	15 to 20	——
,, Central	——	40 to 55
Prussia	20 to 25	52
Italy	35	53 to 63
Hungary	16	54½
Denmark	35	46½
Belgium generally	30 to 40	50
Holland, like Belgium	——	——
India, Calcutta	64	82½
,, Bombay	76	82
,, Delhi	10 to 15	79
,, Birmah	150 to 200	80
,, Ceylon	75 to 85	80 to 82
China	variable	55 to 70
Australia, Sidney	50	62
,, Victoria	30	59
,, S. Australia	17 to 26	65
,, W. Australia	45	65
Tasmania, Hobart Town	40	52
New Zealand, Wellington	29	52
,, Auckland	52	60
Africa, Cape Colony	23	68
,, Natal	large	65
,, Senegambia	190	very high.
,, Senegal	50 to 60	do.
,, Sierra Leone	190 to 310	82
,, Mauritius	12	85
America, Canada West	22	48
,, ,, East	——	42
,, Newfoundland	——	40
,, United States	30 to 70	47 to 60
,, Barbadoes	72	81
,, Jamaica	65 to 70	80
,, Antigua	45	80
,, Bermuda	70	71 to 75
,, Guadeloupe	86	81
,, Trinidad	75	80
,, Guiana	103 to 130	80

From this table some idea may be gathered of the great variety that exists on the surface of the earth, in respect to all conditions of climate, although those of rain-fall and temperature alone have been mentioned. Its value to the intending emigrant, wishing to pursue agriculture, will be due to the choice it affords of those two circumstances; and that choice should be made in accordance with his capabilities of meeting the peculiarities of climate, &c.

A brief *résumé* of the vegetable productions of the different zones of climate, north and south of the equator, may not be without its value to some of our readers. It will apply to all parts of the world, as we shall give the latitudes north and south of the equator, rather than the countries themselves. A reference to the degree of latitude, as marked on any map of the world, will be sufficient to show the various localities that will be generally referred to.

About the equator the heat is great, and the climate hot and moist; hence, there, palms, bananas, spices, ginger, gums, the sugar-cane, dyewoods, cotton, &c., readily grow and flourish. The south West Indian Islands, and Ceylon, fall under the same category of products. At about 15° north and south of the equator, the preceding also grow readily. Tropical fruits of all kinds are reared, with the cocoa-nut, indigo, tobacco, rice, &c.

From 24° to 34°, which, in north latitude, includes India, and the north of Africa, to the products already mentioned, opium and tea may be added. This range includes the chief sugar, tobacco, and cotton-growing countries (as the south of the United States, and India). Amongst fruits and trees, the date, &c., magnolias, large forest trees, with many of the choicest vegetable products, abound.

North of the equator, from latitude 34° to 45°, the warm temperate zone of Portugal, Spain, Greece, Italy, and the south of France occurs, producing the vine, mulberry, olive, cork, chestnut, myrtle, and other plants. Rice is partly grown; and wheat, with other cereal crops, are reared. Amongst fruits are oranges, lemons; many kind of nuts; grapes, for making wine; raisins, as a dessert; currants, for pastry, &c.; peaches; with many other products, with difficulty reared north, except in hot-houses.

Within the limits of from 45° to 58°, our own country, and the greatest, or rather the most important part of continental Europe, is located. Cereal crops grow generally in great abundance, as food for man; grass gives plentiful pasturage for the domestic animals; a great variety of fruits, as the apple, pear, plum, cherry, nuts of many kinds, with numerous others, is largely produced. Amongst the timber trees are the oak, ash, elm, birch, beech, chestnut, walnut, plane, lime or linden, &c. In southern latitudes, the colonised portions of Australia, Tasmania, and New Zealand are included in this zone; and the products of those countries, when cultivated, in most respects resemble our own, with the addition of many indigenous kinds—as, for example, the *Eucalyptus*, or gum tree; acacias, with many forest evergreens.

All the preceding remarks apply chiefly at the sea-level; but, as already pointed out at a previous page, an increase in elevation above the sea varies the products, just as much as a variation of latitude, north or south of the equator, towards the poles. For example, at the hottest portions of the earth, near the equator, where palms, bananas, ginger, spices, &c., are produced, the change of elevation to a point 2,000 to 4,000 feet above the sea-level, brings us to a locality where tree-ferns exist; from 4,000 to 6,000 feet elevation, myrtles, laurels, magnolias, &c., will grow; from 6,000 to 8,000 feet, olives, as in the south of Europe, may be produced; at a height of from 8,000 to 10,000 feet, a climate similar to that of the north of France or the south of England is met with, producing wheat, oak, beech, &c., &c.; and so on, even under the equator, we may gradually rise, until at 16,000 feet, in mountain height, only Arctic plants are met with, and perpetual snow reigns, whilst at the base of such a supposed mountain the hottest part of the world may be found.

We have thus endeavoured to point out some of the most important physical conditions of heat, light, mechanical circumstance, meteorology, and climate, that affect the operations of agriculture and horticulture, not only in our own island, but in all parts of the world. Complex as are the chemical conditions, those of a physical character are scarcely less so. They are, however, more perceptible to the eye and experience of the farmer than those of the chemical kind. The latter pursue their course utterly unseen, except in their results; whilst the physical conditions of agriculture are matters of daily, nay, hourly experience. Hence the complaint of excess of heat producing drought, or its deficiency in impeding the growth of crops: in a less observed degree, the same applies to the effects of light. In respect to the mechanical conditions, ploughing, harrowing, and drainage are the common and essential duties of the farmer; whilst the constant variations of heat and cold, wet and dry, cloud and sunshine, are the meteorological phenomena, so constantly the subject of complaint or thankfulness on the part of the farmer. When we reflect on the immense range of science involved in agriculture, we almost wonder that a blade of grass is grown, an ear of corn reaped, a vegetable cut, or a fruit plucked. Fortunately for man, however, he has comparatively little to do; for the earth, air, heat, light, and water of nature do the most part; and just as one man may steer a ship containing hundreds of human beings and tons of merchandise, not an article of which he could personally, perhaps, carry, so the farmer, amidst all the philosophical congeries of his operations, may be as ignorant as the soil, and yet, by some means—by luck in certain cases, and judgment, aided by science, in others—attain not only personal prosperity, but be the means of feeding hundreds or thousands of his fellow-creatures.

We next turn to the—

Botanical Conditions.

The idea of including botany as an element of the education of the farmer, would, forty years ago, have been scouted as not only a waste of time, but also simply ridiculous. It would have been categorised with chemistry, geology, and science generally, as entirely out of the question, and useless. Modern common sense has reversed that opinion; and, indeed, it is almost amusing at times, by way of contrast, to find hard Latin names escaping the lips of the farmer and horticulturist in describing the various plants each grow and sell.

It will be impossible for us to give more than a very bare outline of botany here; indeed, we shall only deal with the subject just so far as will enable us to bring a few of the most important organs of plants under notice—just so far as that course may be directly conducive to the farmer's interest or requirements; and shall consequently suggest reference to the works of Lindley, Loudon, Smith, and other eminent writers on the subject, to those of our readers desirous of making deeper study. We suggest, however, at the same time, a careful inspection of the contents of the Museum of Economic Botany at Kew, near London, where excellent specimens of nearly every kind of vegetable food used or grown on the face of the globe, may be seen, and where information of the greatest value can be obtained by all interested in the subject.

The whole of the vegetable produce of an ordinary farm may be classed, botanically, under two heads. 1st. Those which, on arising above the earth, present but one leaf growing from the seed, and called *Monocotyledinous*, or *single-leafed*, such as corn of all kinds, and grass; and those that produce at first two leaves, the *Dicotyledinous*, or *two-leafed*, such as the pea, bean, and an immense number of other plants—in fact, in temperate climates, the greater portion of all plants and trees grown.

All plants with stems are similarly divisible into two great classes. One is called *Exogenous*, or such as increase the size of the stem on the outside, as all trees growing in our climate; and the other is termed *Endogenous*, that increase their size internally, are generally of the same diameter in their whole length, and are represented by the palm, and a large proportion of plants cultivated or growing naturally in hot climates. We shall omit all notice of ferns, mosses, and lichens, as not being of practical interest to the farmer.

The seed, as the first form of every plant, requires our notice; and it varies, in its natural state and growth, according as the plant belongs to either of the two pair of classes just mentioned.

In the annexed cut, a monocotyledinous, or single-leafed seed, is represented in the act of growth. It is a seed of common grass, such as is sown for pasturage. Its important points are the following:—*c* represents the single seed-leaf as rising above ground; *p* is the plumule, or growing-point of the stem; and *r* the radicle, or that portion that grows downwards in the earth to collect the mineral food for the plant, as already explained at p. 359, *ante.*

Fig. 318.

Corn of all kinds, as wheat, oats, barley, rye, maize, rice, &c., &c., are represented in their seed-growth by this description.

The seed of the dicotyledonous kind, or those that present two seed-leaves on first growth, differ from the preceding in shape, growth, &c. Thus, in the margin, the seed of the common garden bean, or scarlet-runner, is illustrated. The two seed-leaves, or cotyledons, are shown at *a;* the plumule at *b;* and the radicle, producing the root, at *c.* As the seed germinates, the cotyledons, *a*, rise together through the soil, and, on gaining the open air, burst open, presenting two leaves, as is familiarly known in the growth of peas, beans, lupines, &c. We may here add, that the two pairs of distinctions already pointed out, are thus united. All monocotyledonous plants are *endogenous*, and all dicotyledonous plants are *exogenous.*

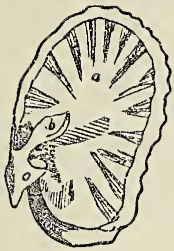


Fig. 319.

The growth of the single-leaf plant, or monocotyledon, is central; that is, the plumule pushes its way up the centre of the plant, covered with a sheath, as may speedily be noticed by examining a stem of grass. If that, or a single blade of corn, be broken open, the inside, or endogenous mode of growth, until the flower and seed appear, will be very evident.

Not so, however, with the growth of a two-leafed, dicotyledonous and exogenous plant. We will take, for example, the scarlet-runner, which represents any or every other of such plants, and is illustrated in the annexed cut. In it we find four parts of importance. In the first place, are the two seed-leaves, as they appear at early growth of the plant, as seen at *c c.* Next is the plumule, or growing part of the stem, shown at *a*, and which gradually increases in height, throwing out leaves from the side of the stem—of which it is a continuation—right and left. Next in order we have the stem, extending from *a* to *b;* the latter being called the *collum*, and uniting the upper part of the plant with that below ground. Lastly, at *d*, we perceive the root, or radicle, with the rootlets, or little roots, extending in all directions in search of moisture and mineral food, that they collect from the soil.

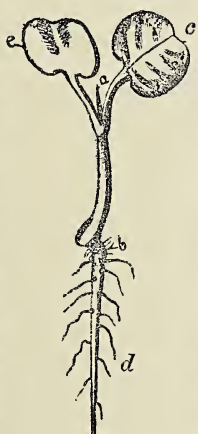


Fig. 320.

As such a plant grows, the plumule, as it lengthens, forms, at different parts, a kind of projection called a node; and this is where the succeeding sets of leaves, above the first set, are constantly formed. In grasses these are readily distinguished as so many joints of the stem.

As soon as the first leaves of the plant emerge into the air, then the process of circulation of the sap goes on. There is an exact resemblance between the blood of animals and the sap of plants. In the first place, both possess a circulating power; secondly, the sap and blood equally carry nutriment to every part of either the plant or animal, replacing parts, enlarging them, or producing fresh. Indeed, the subject of comparative physiology, in respect to plants and animals, is full of such analogies, not only as regards the organs of circulation, but also in respect to respiration, perspiration, and other functions common to both. The study is one of the highest interest; but for want of space we can but very briefly glance at it. Some few of the analogies presented by the subject will be evident as we proceed.

First, we may notice the skin, or cuticle, of herbs, the seat of their respiration and digestion, and the means by which they gather the carbon from the carbonic acid of the air, as already, in part, explained at p. 357, *ante.* This cuticle consists of two layers—namely, an epidermis, or scarf-skin, and a true skin, with stomata, or mouths, hairs, prickles, warts, and places to hold the secretions. Hence we see that the leaves and stem of such plants serve the purpose of the lungs and stomach of the animal.

The stomata are mouths by which the plant carries on respiration; and they consist of small openings into, and channels through the epidermis. They are usually circular or oval; but there are other forms of them. Their number on a leaf is something astonishing, varying, on each square inch of surface, from a few hundred to 160,000. They open and close, admitting air to the sap; and thus, as before stated, they fill not only the precise office of the animal lung, but perform the duty in a similar manner. As a rule, they abound only on the under-surface of the leaf; and thus dust is kept from choking their minute apertures, and the moisture is not readily evaporated by the rays of the sun. In this lower position, under the leaf, they readily absorb the watery vapour that rises from the ground, and which is essential to their existence and growth.

Some very interesting points of chemical philosophy are involved in the respiration and digestion of plants by means of the stomata, that require special notice here, although before alluded to, and that are remarkably like the similar processes of animals, but with a reverse effect as regards the products of respiration.

The carbonic acid of the air, constantly present in minute quantities everywhere, but especially so near towns—whence its proportion is locally much increased by coal fires, and the respiration of the inhabitants—is composed of two equivalents of oxygen, united with one of carbon. In other words, twenty-two pounds of carbonic acid contain six pounds of carbon, united with sixteen pounds of oxygen.

Now, during daylight, this carbonic acid, absorbed into the stomata, undergoes decomposition. The carbon becomes converted into the tissue, &c., of the plant by the vital and che-

mical action of its organs; but the oxygen is excreted in the form of gas, and passes off again into the air. This may be readily seen by putting a sprig of mint into a glass tumbler. This is to be filled with water; a plate may then be put over, and by dexterously turning it upside down, all the water may be kept in the tumbler. It is next to be exposed to the rays of the sun, and, after a little time, small bubbles of gas will appear on the leaves of the mint. These bubbles consist of pure oxygen, which, by care and practised manipulation with gases, might be collected and tested in the usual way, when its effects of increasing the light of a burning body, or of re-igniting a smouldering match, would be at once apparent.

The results of animal nutrition and respiration are the reverse of the preceding. The food taken into the stomach undergoes solution by the gastric juice, being gradually converted into chyle. This is absorbed by minute vessels, analogous to the stomata of plants, and carried, by the thoracic duct, to the lungs, being there converted into blood. It is in this condition called venous blood, and is of a dark colour. But no sooner does it get into contact with the air drawn on to the lungs by the process of respiration, than it becomes oxidised (see *ante*, p. 355). The carbon is slowly burnt, producing heat to the animal, and carbonic acid is thrown off by the breath passing from the animal into the atmosphere by the mouth. This carbonic acid is deadly poisonous if breathed by the animal, but is an essential food for the plant, which, in its turn, as already described, decomposes it, returning its oxygen again to the animal, who could not respire, digest, or exist without oxygen.

We cannot spare space to enter into a description of the various organs of plants, a knowledge of which, indeed, would be of no practical value to the farmer; and it is for this reason that we restrict ourselves only to such matters of botany, a knowledge of which is essential to the purpose of this work.

What has already been stated is applicable generally to all the plants grown by the farmer that have stems above ground, such as the grasses, corn of all kinds, fruit and forest trees. But there is another class of plants to which we must allude, and these have under-ground stems, such as the potato, turnip, carrot, onion, and others of a similar form.

A common error is that of considering the potato, as taken from the earth, to be either a

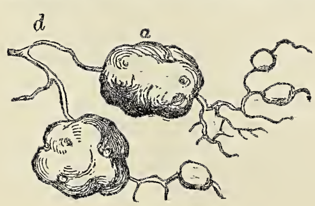


Fig. 321.

fruit or a root. It is neither; but simply an enlargement of the stem. Thus, in the above cut the growth of an ordinary potato is represented, *a* being the tuber, or potato, and *b* fibres connecting them together, or to the stem growing above ground: the real root proceeds from the potato downwards or sideways, just as all other roots do; and the same remark is equally applicable to the turnip, onion, &c.

On cutting open the tuber, or potato, it will be seen composed of a great number of cells, that contain starch, having no resemblance whatever to seed or fruit. Still better is the examination made by a microscope, when the cellular tissue will be at once apparent if a thin slice be used. Comparing its structure with any seed, the difference will be at once apparent.

By reference to p. 362, *ante*, again, the chemical character of these tubers will be seen to differ entirely from all seed. They are chiefly composed of water, with a variable proportion of starch, replaced in the stems of trees by woody fibre. The stem of the sago palm is, like the stem or tuber of the potato plant, a great producer of starch.

In cases of disease, especially the potato disease, the cells of starch in the tuber break up, and are completely obliterated, becoming a confused unorganised mass. The changes that it undergoes are both chemical and mechanical; and, if all the starch cells be destroyed, the tuber becomes valueless as an article of food for man and beast.

The stems of trees present some beautiful objects for study in their construction and growth. A thin slice of one, examined by the microscope, will present a number of rings, showing the yearly growth of the plant, one being added each year; and hence giving us a means of approximatively ascertaining the age of the tree, by counting the number of the rings from the pith to the outside. The pith occupies the centre of the stem; in some, as the elder, remaining throughout the growth of the tree; but, in most cases, becomes absorbed and invisible.

Although the great object of farming operations is the production of seed, still the actual growth of that object is one of pure nature, unaided by man, except so far as he tills the ground, sows the first seed in good ground, and adds the manure requisite for full and prolific growth. We shall therefore not enter into the examination of that part of a plant where the seed is produced; as, although of great interest, it has no practical bearing on our subject.

Suffice it to say, that all seed and fruit-bearing plants are provided, in the flower, with reproductive organs. The male flower affords the pollen, which causes the production of the seed in the female flower. The latter is provided with organs exceedingly similar, in construction and general arrangement, to those of the female animal; as, for example, the ovary, placenta, &c.—names that have been applied to such parts of plants because of their general resemblance, in construction and office, to those similarly called in animals. Indeed, the process of generating the seed by the pollen also greatly resembles that of the animal; for as soon as the

fructifying process commences, a connection is established by minute tubes, called pollen tubes, with terminals in the placenta, and, under it, with the embryo and the pollen, or the pistil. On this curious and beautiful contrivance, Dr. Smith, the eminent botanist, remarks :—

"How minute and wonderful are the structures, and their functions, found in vegetables !—equally so with anything known in the animal creation. Thus all the parts of a plant, external to the stamen [the male organ], are created in perfect subserviency to the functions of that organ ; and of the stamen itself, how small a portion seems to be essential. The filament supports the anther ; the anther incloses the pollen ; the cell-walls of the pollen inclose a little matter ; and it is only a part of that ultimate production which is essential to the function for which the plant was created."

We shall not at all enter into any description of the different systems of botany that have been proposed, by which to classify plants. If we shall require, in future pages, to use any such classification, the *Natural order*, as adopted at Kew, in the arrangement of the Museum of Economic Botany, will be adopted. The principles of this order are briefly enunciated in the introductory remarks to the catalogue of that museum, arranged under the superintendence of the late Sir William Hooker, and his son, Dr. Hooker. The remarks, descriptive of the natural order they followed, are—

"The orders may be compared to families. They are, in some cases, very large ; in others, comparatively small. Some abound in economic products, while others afford but few.

"Between members of each order (or *family*), the rule is, that a closer relationship subsists than with the members of another order. This relationship or affinity is reckoned by the amount of similarity, chiefly in the form and arrangement of the parts of the flower and seed ; and the correctness of this method is confirmed by a remarkable general and corresponding uniformity in the character of the products and properties of the plants thus brought together. For example, note the tough Barks of the 'Nettle' order, the 'Mezereon' order, the 'Linden' and 'Mallow' orders ; the Bitter and Tonic properties of the 'Gentian' order, the 'Quassia' and 'Peruvian Bark' orders ; the Resins of the 'Amyris,' or 'Frankincense,' and the 'Pine' orders ; the Narcotic and Poisonous character of the 'Nightshade' order, which includes the deadly nightshade, henbane, and tobacco : the fruit, too, of the common potato, another of its members, is well known to be dangerous."

At p. 362, *ante*, and subsequent pages, the leading proximate principles of plants have been detailed ; such as starch, gum, sugar, &c.—those there mentioned being of most importance to the farmer. Others, such as india-rubber, gutta-percha, aromatic substances, perfumed or volatile oils, tar, pitch, resin, colouring matter for dyestuffs, drugs, acids, tannin, or astringent matter (already more fully noticed), together with the products of mosses, lichens, &c., may be dismissed by thus simply naming them ; because, although important products in many parts, and affording great employment in certain peculiar kinds of farms abroad, they are not so raised in our islands.

We have thus endeavoured to present an outline of those geological, chemical, physical, and botanical conditions, or principles, of most vital interest to the farmer, and a knowledge of which is undoubtedly of the highest importance to all who would conduct their operations on sound principles, consistent with the discoveries of modern science.

The limits of our space forbid a further enlargement on the various subjects that have passed under review ; but sufficient has, we believe, been advanced to put the intelligent reader in possession of the most important subjects, and the leading principles of each ; and further information may be readily gained from works that are specially devoted to each subject. The difficulty experienced by persons strange to science, in commencing its study, generally arises from the technical phrases employed, and the crowding of too many facts on the mind at a time. When a person has gained a little knowledge of a subject, and is desirous of obtaining more, little difficulty is experienced, except at the outset, for then the interest he takes in the matter makes the labour easy. So as not to confuse the readers for whom this work is intended, by a multiplicity of facts barely relevant, we have only brought forward such as are of practical value, and can —nay, must—be applied on the farm.

As we proceed in describing the modern methods of practical farming, the value of a knowledge of such principles will become more apparent, because their individual application will be perceived ; and the brief outline that has been given in these pages will serve as indicative and suggestive of further inquiry on the part of the practical reader.

What has been already adduced has, in most cases, a practical application, not only to farming in our islands, but also to any cultivation of the soil in all climates. And here we may remark on the great value of such knowledge as we have been dealing with, to persons about to emigrate to distant lands. We can well remember the fearful, and occasionally fatal, mistakes that attended emigration to Australia forty years ago. Almost every class of persons who could find the means, was represented amongst the early emigrants to Adelaide, and other Australian colonies ; New Zealand and Tasmania. Many—nay, most—were entirely ignorant of what they could do when they arrived at their destination ; and an equal number were utterly incapable of carrying out their proposed occupation in life. One instance came under our notice, of an individual who had failed in the drapery trade for a large amount, and determined, with what little money he had left, to commence farming. His fitness for that occupation may be judged of by the fact, that when asked the name of a crop in separate fields,

before leaving England, he stated a potato field to be one of wheat.

But, supposing the case of an able farmer emigrating, the least he could do, as a man of sense, would be to acquaint himself, as far as possible, with the nature of the soil, climate, products, and other peculiarities of the country he is proceeding to. Having obtained this information, a knowledge of geology, chemistry, botany, and a little natural philosophy, would enable him, on landing, first to invest his money judiciously on good land, and, afterwards, to turn that land to the best possible account. The value of such knowledge may be estimated by the fact, that the early producers of "greens," in some of the colonies we have named, got almost as much profit by the sale of them as some of the most successful gold-diggers. True it is that knowledge is power; and the more of that power a man possesses, especially in agricultural pursuits, the greater will be his capability of extracting riches from nature, and benefiting himself, his family, and his surrounding neighbours. A few enterprising and intelligent men of that class would do more for a colony than all the gold that could be discovered, for their pursuits afford permanent means of riches, whilst the discovery of the metal must, in its results, be but temporary, and at last fail.

THE CHEMICAL ANALYSIS OF SOILS, MANURES, ETC.

In previous pages, the importance of a chemical analysis of soil has been pointed out, more especially under the head of the *Chemical Conditions* of agriculture (see p. 354, *et seq.*) We accordingly proceed to give such instructions, presumably to those quite unacquainted with chemistry, as may enable them to become, to a certain degree, acquainted with methods which, perfected after the gathering of first knowledge, may result in the highest practical value.

But we must precede such instructions by first mentioning a certain amount of apparatus that will be requisite to carry them out; for such are as much the tools of the laboratory, large or small, of the agriculturist or the practical chemist, as are the spade, plough, harrow, &c., on the farm.

One of the earliest operations of a soil-analysis, is that of driving off unnecessary moisture; by which we mean, that, separated from the soil, it does not affect its composition in a chemical point of view; although, practically, as we have shown at p. 371, *ante*, it is of the highest importance in promoting germination of the seed, and growth of the plant.

For this purpose, evaporating dishes may be used, together with what is called, by chemists, a *water*-bath. These may be cheaply purchased at any experimental or operative chemist's, or at most opticians' shops. But, in the absence of such, the following plan may be adopted:—

The soil to be dried is first broken up into a coarse powder, and put into a basin of earthenware. This is to be put into a saucepan so full of water that the basin may rest, to the extent of two-thirds of its depth, in the fluid. The saucepan being then placed on an ordinary fire, and the water being allowed to boil, will afford a temperature never exceeding about 212°, or the boiling-point of water. By this precaution, adding also water as it boils away, all chance of chemical decomposition, except in certain special cases, will be prevented, and one element of error in organic analysis avoided.

Next in point of importance, or, perhaps, order of operation, is that of solution; for chemical analysis is barely possible of being carried out until the bodies to be examined have been dissolved. In nearly every instance, the chemist depends on being able to throw down, from *solution*, insoluble substances that, by their colour and other properties, lead him to a knowledge of what every substance he investigates contains.

One of the best and cheapest instruments of solution, is the common, thin, pear-shaped Florence flask, that are sold containing salad oil, but may be bought empty, at a penny a-piece, in almost any part of our islands. Such flasks are easily cleansed by pouring into them about half a wine-glassful of strong sulphuric acid (oil of vitriol). This should be allowed to run over all the inside of the flask, which is easily done by turning it in different directions. The acid will turn black, owing to the decomposition of the oil; and when all oily stains disappear, it may be poured away. The flask should then be washed out with a little hot water and soda; next with water; and turned upside down, it will speedily dry.

Heat is required to effect solution; and, for this purpose, the chemist usually employs a Bunsen's gas-lamp. But a common cheap paraffin glass-lamp, with its wick, and charged with methylated spirits, for cheapness' sake, will answer every purpose. These are sold, at about 6*d.* or 8*d.* each, in almost every town; and answer every purpose of the "spirit-lamp" sold by operative chemists. Even the flame of gas, oil-lamp, or candle will answer all usual purposes of heating a liquid for solution.

Next in cheapness and utility to the Florence flask, is the test-tube. It is made of thin glass, and varies in diameter from, say half an inch, with a length of two inches upwards. One of

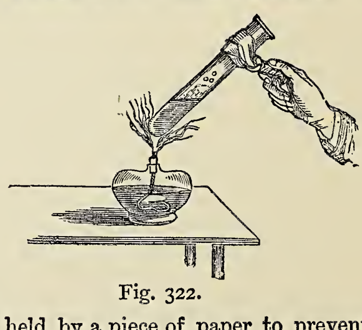


Fig. 322.

these, held by a piece of paper to prevent heat passing to the hand, is represented over the

flame of a spirit-lamp in the preceding cut. In such a vessel, solution, precipitation, &c., &c., may be most conveniently carried on. In fact, the accomplished experimental chemist, with a few test-tubes, watch-glasses, and other such trifling matters, can run through almost all branches of chemical science, for analysis or demonstration, with ease and convenience. Generally, indeed, those who know most of experimental philosophy, require the fewest and simplest apparatus; whilst the beginner, ignorant of many contrivances, must have recourse to the instrument-maker for aid that the practical man knows how to provide for himself. Practice makes perfect.

For breaking up masses, a pestle and mortar are necessary. For filtration, a funnel, stand, and porous paper (white blotting-paper) are requisite. Crucibles are needed for fusion; whilst a common fireplace or grate, fed with cinders or coke, will answer very well for a furnace. The oven used to bake bread may also be made a source of heat for solution. The following apparatus may be purchased in any part of the kingdom, of an operative chemist, for £1 5*s.* (as from Griffin, How, Horne and Thornthwaite, or any other instrument-maker in London or the country). The list, made from Griffin's catalogue (London), includes all matters necessary for qualitative analysis, except the chemicals, of which we shall speak hereafter, and that are exceedingly cheap; and a balance for weighing, which is a somewhat expensive article.

List of Apparatus for Qualitative Analysis.

Spirit-lamp, wick, and spirits of wine, or methylated spirit.
Retort-stand, with rings.
Sand and water-baths.
Blowpipe, platina foil, and wire.
Crucibles, English, and Berlin porcelain.
Tongs, spatula, and file.
Porcelain mortar and pestle.
Beaker-glasses.
Porcelain basins for evaporation.
Florence flasks.
Washing-bottle.
Test-tubes.
Watch-glasses.
Glass stirrers.
Test-papers.
India-rubber tubing, and glass tube.
Funnels and filtering-paper.
Bottles to contain acids and tests; those containing acid to be glass stoppered.

The preceding list is that of apparatus required at Guy's Hospital, London, for classes in practical chemistry, slightly modified by us for the more special requirement of the farmer; sold by Messrs. Griffin, Garrick Street, Soho, London, and packed in a case; who, with most other instrument makers, fit up every sized case of apparatus to order. Each of the above, however, may be purchased separately, according as they may be required, either at first, or to replace broken articles.

Provided with the apparatus just mentioned, the farmer, even unacquainted with chemical science, may make a fair start in discovering the constituents of his soils, provided he carefully attend to the directions that are now to be given. Failing in the want of experience of the practical chemist, he may make many stumbles or errors at first; but a little perseverance and due attention will soon tide him over all his difficulties.

In the practical part of our subject, and of a general nature in its application, we must first remark, that in nearly every chemical analysis, whilst the first step is the solution of a body, or a number of them, the next is to deal with each of those constituents successively, in such a manner that they may be separated without interfering with each other; and herein lies the art of chemical analysis.

Supposing, for example, to be simple in our illustration, that any specimen of soil contained, as its chief minerals, silica, alumina, lime, and iron—substances, with many others, already described at p. 358, and subsequent pages, and shown to be present in wheat at p. 347, *ante.* Now the separation of them by one process would be impossible, for these reasons — the silica, insoluble in nearly every menstruum that the chemist knows, is readily removed by dissolving away *from it* all the other substances that would consequently leave it as an insoluble powder. Thus, in the supposed soils, the alumina (or much of it), the lime, and iron, would readily dissolve in dilute hydrochloric acid, aided by heat.

The action of this acid would be, then, to form a reddish-brown solution, in which the alumina, lime, and iron would be perfectly undistinguishable, except that the presence of the latter element gives a reddish colour to the solution.

But the chemist is enabled to separate these substances to an almost exact degree of accuracy. Thus, anticipating slightly the more precise details that have to be given, he would proceed as follows, in order.

Having dissolved the soil in hydrochloric acid and water, with the addition, perhaps, of a little nitric acid, and the assistance of heat, applied to the flask containing the substances, distilled water would be added, to dilute the solution. The insoluble matter would be filtered away, and kept for weighing as silica. That would remove one element. Next, the clear solution is tested as follows:—Liquid ammonia is added, the liquid being stirred until no more precipitate or solid matter is thrown down. This latter is then filtered off, washed, and put into another vessel (the original solution being carefully preserved for other operations). The solid so obtained on the filter consists of iron and alumina. Both are soluble in hydrochloric acid, as already stated; and the solid is therefore dissolved therein. Caustic potass in solution is then added to excess; and it at first throws down both the iron and alumina; but gradually the alumina is re-dissolved, and so the iron is left as a reddish-brown powder, or becomes so on exposure to the air.

Thus the iron and silica have been separated. From the potass solution just named, sal-ammoniac (after removal of the oxide of iron by filtration) will throw down the alumina; and thus three out of the four bodies present in the soil will be removed.

Lastly, if to the original solution—that is, after the removal of the silica by filtration—a solution of the oxalate of ammonia be added, the lime present will be precipitated, or thrown down as an oxalate. Thus the chemist, from the first solution of all soluble substances in the soil, not only separates and obtains them in a solid state, but also does so in such a form, that by proper precautions he may weigh them, and ascertain, with great accuracy, the proportion of each present.

Such is a brief outline of an easy problem in agricultural chemistry, and one that it is advisable for the farmer frequently to repeat, so as to get some idea of the method of carrying on an analysis. There are few, if any, soils in this kingdom destitute entirely of the substances that have been named, and our rough illustration may be readily carried out in practice.

We must next enter into more minute details of agricultural analysis; and, referring to p. 347, *ante*, it will be seen that only a portion of the essential constituents of soils has been named.

We there notice that nine different elementary bodies—potassium and sodium, or oxides, as potash and soda, being alkalies; calcium and magnesium, or as oxides of those metals, affording the earths lime and magnesia; the metal iron; with the non-metallic elements, phosphorus, sulphur, chlorine, and silica—are reckoned to be the mineral constituents that a crop of wheat, with its straw, abstracts from the soil. Besides which, oxygen and hydrogen, as water, with nitrogen and carbon, must be included as the food of a wheat plant.

It will also be noticed that different plants require varied articles of mineral food. Thus, silica is highly characteristic of wheat and all other corn crops; forming, in fact, above 50 per cent. of their ash or mineral matter on their being calcined. On the other hand, peas, beans, and other leguminous plants, are equally characterised as requiring much lime, affording, on being calcined, at least 50 per cent. of that earth as their ash. Lastly, potato, turnip, carrot, and other such tuber plants, are characterised by requiring potash, the ash of some of them giving from 70 to 80 per cent. of that alkali or its salts.

From these facts it is evident that a careful qualitative and quantitative analysis of a soil is of the utmost importance. It is not sufficient that almost all of the necessary constituents for the growth of a plant be present. Unless all are existing in the soil, the latter undergoes rapid exhaustion, followed, of course, by rapidly advancing infertility or barrenness. It is from this fact that, formerly, a system of rotation of crop and fallowing became adopted, and frequently compulsory on the farmer; and that, recently, chemical analysis has been largely employed to discover the loss that the soil sustains by each crop, and also to replace such loss.

Taking the more extended list of substances that have to be sought for, and having already demonstrated how silica, lime, alumina, and iron may be detected in soils, we proceed to give general directions for the discovery, qualitatively, of those recently mentioned—such as magnesia, the alkalies, phosphorus, sulphur, &c.

Potassium, sodium, magnesium, phosphorus, sulphur, and chlorine, like lime, &c. (already referred to in respect to its detection), are always found in combination with other bodies, and mostly as salts. Thus sodium and potassium are generally discovered as chlorides of those metals (that is, in combination with chlorine), or as the sulphate, carbonate, &c., of soda and potash respectively.

Chlorine is found in combination with the metals just named, especially as affording common salt, when combined with sodium, as the chloride of sodium—a most essential addition as a manure to most soils.

Phosphorus and sulphur are found also in combination of a double kind. First chemically, as the phosphoric and sulphuric acids; and, next, both naturally and chemically, as phosphate of lime, &c.; or sulphate of lime, soda, magnesia, and of other bases; and it is in this form that they have to be dealt with analytically,

We have already pointed out, at p. 379, *ante*, that it is the object of the chemist to remove by analysis, whenever possible, the substance in a solid state; and it has been also shown, that silica, lime, iron, and alumina are thus easily detected and removed. In respect to the bodies with which we are now dealing, some of them present little difficulty. Thus magnesia, if in solution, may be precipitated, after the removal of silica, lime, iron, and alumina, from such a solution as we supposed at p. 379, *ante*, by the addition of liquid ammonia and a solution of phosphate of soda, when a double phosphate of magnesia and ammonia is afforded as an insoluble precipitate. Therefore, by the directions already given, and those now stated, silica, lime, iron, alumina, and magnesia may be eliminated or removed, in the solid form, by precipitation from solutions.

Sulphur, as just stated, is always discovered (except in the form of sulphuretted hydrogen) as a sulphate; and the sulphuric acid, in such a salt, is readily precipitated by the addition of chloride of barium, or dilute solution of nitrate of baryta, when an insoluble sulphate of baryta is afforded; by the weighing of which, the amount of sulphur, or sulphuric acid, can be quantitatively estimated. The great insolubility of sulphate of lime, also renders the detection of that salt, almost constantly present in most soils, easy.

Phosphorus may, like sulphur, be detected by its insoluble precipitates, as salts of lime, magnesia, &c.; and its amount present in any salt is thus readily detected.

Chlorine is easily precipitated from its chlorides, as those of potassium, sodium, magnesium, &c., by the addition, as a test, of nitrate of silver in solution; the metal uniting with the

chlorine to form an insoluble chloride of silver, that is characterised by turning black on exposure to light, especially of the direct rays of the sun.

The greatest difficulty to an unpractised hand, is that of detecting the potash and soda in a soil; because nearly every combination of both is freely soluble in water, and cannot be precipitated. Potass, however, in the form of chloride of potassium, forms with the chloride of platinum a double salt, by which we are enabled to separate the potassium, and so estimate the potash in a soil, or the ash of a plant; whilst the only insoluble salts of soda is an antimoniate, which is so unmanageable as to leave the detection of soda to other and more certain methods.

As it would be impossible, in this work, to enter into all the minutiæ of chemical analysis in regard to soils and the ashes of plants, we must content ourselves with a brief outline of the principal points of importance in respect to both qualitative and quantitative analysis, presuming almost entire ignorance, on the part of our agricultural readers, of chemical science and manipulation. We shall therefore only attempt to lead them to the threshold of the subject; and leave to practice, careful study, and the perusal of such works as those of Rose, Normandy, Brande, Turner, Miller, Fresenius, and other writers on chemistry, the perfecting of what we only hope to originate—careful analysis as applied in the farm.

Taking, first, the rough analysis of soil, it must be remarked, that if an idea as to the average agricultural value of a field is desired, care must be taken to make the material an average by selecting portions from all parts. But this plan is liable to error; for it may happen that two entirely different geological strata occur in the same field or estate. The farmer must be very careful on this point, or chemical analysis may lead him into the most egregious error. The rule should therefore be, to take several samples of earth dug from about a foot down, including the surface of such parts of the field, &c., as appear similar in character; and if any great diversity exist, the estate or field should be considered divided into separate districts, each requiring distinct chemical analysis to discover its individual peculiarities. From this plan great advantage may arise; for, by judicious selection, one field or district may make up the deficiencies of another—a circumstance that commonly occurs on large farms. We have frequently seen marly, sandy, and clayey lands forming distinct portions of a country, district, or large estate, the mixture of the soil of which became very beneficial.

A pound or two, from various portions of the soil, having been selected, of as near as possible similar constitution, the whole should be well mixed together, and dried in the sun, if possible, until all moisture has evaporated; but if the sun be not favourable to such an operation—as in winter, for example, or wet weather—this drying may be effected in front of a common fire; the temperature of the specimen earth never being allowed greater than the hand can bear in touching it.

The object of this is as follows:—Soils greatly differ in their power of absorbing and retaining moisture. Thus sand will apparently absorb any amount of water, but has no power of retaining it; whilst clay has precisely opposite qualities, absorbing very slowly, but retaining very long, any water with which it may get in contact.

The soil being quite dry, is then to be sifted through a sieve to remove all stones, which have only a most remote chemical influence, although, mechanically, they are valuable as assisting the drainage of the land. Masses of hard earth must not be removed, but should be pounded in a mortar, then sifted, and added to the powdered soil already passed through the sieve.

By such means an average of the food-soil of the land may be obtained in a dried state. It is next advisable to proceed as follows, to judge of the absorbent and retentive power of the soil, which are purely physical conditions, yet of the highest agricultural importance.

About four or five pounds' weight of the dry soil may then be put into a vessel, perforated at the bottom with fine holes, such as a porcelain or metal colander, and water is gently to be poured on to the soil until it is *completely* wetted in every part. Any water that will may be allowed to drip off: and this having been finished, the mass is to be weighed. The weight, additional to that of the original weight of the dry soil, will indicate the amount of water it can take up and retain. By drying it again in the sun or before a fire, as previously directed, will show how long such soil will retain moisture; and great difference will be found in both respects between sandy, marly, clayey, and loamy soils. The indications so afforded will be a guide, in some degree, to the requirement of drainage of the soil that is in course of examination; because, by such processes as we have described, the effects of air, heat, &c., on the soil have only been hastened, rather than varied from those naturally in operation in the field. At the same time a general idea of the mechanical condition of the soil is gained; as, for example, its porosity, friability, denseness, and other conditions already entered into, under the head of Physical Conditions, *ante*, at p. 365, and subsequent pages.

Some persons recommend that the specific gravity of the soil should be taken. This plan may have remote advantages for the purpose of comparison, but the results are rather of a scientific than practical character in most cases; and much care is required to obtain any degree of accuracy, especially if any soluble matter be present. We shall therefore pass on to consider matters of greater importance.

If on the same farm different kinds of soil exist, their comparative absorbent and retentive power may be examined, by pursuing the same course with specimens of each kind, and putting the results of one against the other, and possibly valuable hints may be gained as to the propriety of mixing such soils for mechanical objects; as, for example, adding lime and sand to clay,

or *vice versâ*, according to the peculiarities of each.

By examining the dried specimens with a powerful magnifying-glass, it will be seen whether any fibres of plants are present. If a small portion of the earth be heated strongly in a test-tube, and acid-smelling vapours be given off, undecomposed vegetable matters must be present. If, on the other hand, the soil be similarly heated with a little lime, and ammonia be given off, which may also be detected by the smell, animal matter, or, at all events, nitrogen, must exist in the soil. Instead of by the smell, both acid and the ammonia may be detected as follows :—Hold a little moistened litmus paper (made by soaking a piece of white blotting-paper in a solution of litmus or orchil) over the tube. If it turn red, vegetable matter is present. On the other hand, this paper, reddened with an acid, will turn blue if ammonia be present; or a piece of paper dyed with turmeric, will, in the latter case, turn to a reddish-brown. A glass rod, dipped first into hydrochloric acid, and then held over the tube, will indicate the presence of ammonia, by affording copious white vapours of sal-ammoniac.

The next step is to bring into solution such solid matters as will dissolve in water, as the chlorides, sulphates, carbonates, &c., which the soil may contain; and the beginner will act wisely to do this by repeated experiments, rather than by attempting to effect the purpose with one specimen of the soil alone. This will be much the easiest plan for one not used to chemical manipulation.

For example, 100 grains of the dry soil, freed from stones, may be put into a Florence flask (see *ante*, p. 378), and well shaken up for some time with a quarter of a pint of *distilled* water. The reason of using distilled water is, that all ordinary water contains most of the soluble salts that may be expected in the soil; and hence, if that were used, an erroneous result would be arrived at.

Distilled water, if no place for its purchase be near, may be made by attaching four or six feet of clean tin gas-tubing to the spout of a common kettle filled with water. Placed on a fire, the water, as converted into steam, will pass into the metal tube, which should be covered with cloths kept wetted by cold water. This will condense the steam, and so afford water free from saline matter.

Slowly the soluble salts in the soil will be dissolved, and the solution so produced may, for our purpose, be called *a*.

Another 100 grains of the soil are to be boiled, for half-an-hour, with a quarter of a pint of distilled water; and this solution may be called *b*.

From either solution evidence may be obtained of the presence of dissolved matter, by putting a few drops on a piece of perfectly clean window-glass, or platina foil. This is to be held over the flame of a spirit-lamp or candle; and if, after the water has evaporated off, a white or coloured stain is left, then some solid matter must have been dissolved. The solution may be poured into test-tubes, which should be about one quarter filled, and they are to be tested as follows, for both *a* and *b* solutions :—

1. Add a few drops of a solution of chloride of barium. If a white precipitate fall down, sulphuric acid is present, most probably as sulphate of lime, especially if a clayey soil is examined. If it be sulphate of lime that is present, this may be approximately ascertained by boiling the contents of another test-tube, of the solution *a*, to dryness; when, if on the addition of a *few drops* of water, the solid matter *does not* dissolve, it may be considered as sulphate of lime. But if an excess of carbonic acid be present, chalk will remain in solution in the cold solution *a*, but not in *b*; because, by boiling, the carbonic acid holding the chalk dissolved will have been dissipated. To distinguish the sulphate from the carbonate, add one drop of hydrochloric acid to the solid obtained in the tube by evaporation. If no effervescence or escape of gas occur, then the presence of sulphate of lime is most probable; if effervescence occur under the circumstances already related, then the solid matter may be chalk, or carbonate of lime, obtainable only, however, from the cold solution *a*.

Another test-tube, with either *a* or *b* solution, may be tested with a solution of nitrate of silver. If a white curdy-looking precipitate be afforded, some chloride, most probably common salt, is present in the soil; that is, the chloride of sodium. If, on evaporating a small quantity of the solution, the powder formed tinges the blue flame of a candle yellow, a salt of soda must be present. If the flame be more of a violet colour, most likely a salt of potass is afforded.

The most probable constituents of the solution effected by cold or hot water, will therefore be sulphate of lime, carbonate of lime; chlorine, and sulphuric acid, in combination with the alkaline metals or earths, as chlorides of potassium and sodium, or sulphates of potass and soda; and also the carbonates of both alkalies. Possibly the chloride of magnesium, and the sulphate of magnesia, may be also present; but with these we shall deal hereafter.

By the methods already suggested, we may suppose that the cold and hot water have extracted all the substances soluble in that fluid, likely to be met with in ordinary soils. More rarely, nitrates of the alkalies, at least, may be present; but the amount of them is, except under extraordinary circumstances, small in natural and unmanured soil, with which at present we are alone dealing.

The next step will be to bring into solution, by way of the use of acids, various substances that are insoluble in water. For this purpose fifty grains of the dried earth may be put into a Florence flask, with two ounces of hydrochloric acid, and about half that quantity of nitric acid, two ounces of distilled water being added.

The whole should be gradually heated by the spirit-lamp till the mixture boils, in which condition it may be kept for ten minutes. By this the iron, alumina, lime, magnesia, and most

metallic oxides, &c., are brought into solution, that water alone cannot effect. By the application of proper tests, these various bodies have next to be precipitated in succession.

Distilled water should be added when the solution has become cold, so as to fill the Florence flask to the extent of two-thirds of its capacity. A piece of filtering-paper is then to be put into a glass funnel, which may rest in the neck of a tall glass jar, or wide-mouthed bottle.

The filter having been first wetted with a little water, the contents of the flask are to be gently poured into it, both solid and liquid; and to remove any of the former that may remain, the flask is to be rinsed out with distilled water, the rinsings being afterwards poured into the funnel.

The clear liquid that runs into the glass below the funnel will contain all the substances dissolved by the acids; whilst the solid matter left in the filter may be reckoned as silica, or the matter of flint. The silica is thus removed from the solution as one element of the soil.

The clear solution, which we shall call *c*, in the lower glass, is next to be tested for iron, alumina, lime, magnesia, &c.; and as the present directions are only given for qualitative analysis—that is, simply to show what is in the solution, but not how much—a portion of it may be taken (say a fourth part), which is to be put into a clean glass vessel, and tested as follows:—

Pour in liquid ammonia, with constant stirring, until nothing more falls down. The precipitate will be a mixed one of oxide of iron and alumina, if both be present. The contents of this glass are next to be filtered, washed, and the solid matter transferred to another glass vessel containing a little distilled water. Hydrochloric acid is to be added to this until all is dissolved. Caustic potass, in solution, is to be added *in excess*, when the iron will be precipitated as oxide, leaving the alumina in solution with the potass.

This solution is then to be filtered off from the iron, and a solution of sal-ammoniac added. The alumina will then be thrown down as an insoluble white matter.

By the steps already advised, three results of chemical analysis will thus have been attained—namely, the removal of the silica, iron, and alumina.

It will now be desirable to reduce the bulk of the remaining liquid, which should be done by heating it in an evaporating dish until only about four ounces of liquid is left. This is to be poured into a clean glass when cool, to be tested as follows:—

Add, first, a solution of oxalate of ammonia. If lime be present, it will be thrown down as oxalate of lime, an insoluble white powder.

Lastly, the solution being filtered from the last precipitate, is to be tested for magnesia by adding to it, together, liquid ammonia and a solution of phosphate of soda. If magnesia be present, it will be precipitated as a double phosphate of magnesia and ammonia.

Five elements of the soil, of a mineral nature—that is, the oxides of calcium or lime, of magnesium or magnesia, of iron, the alumina, and silica—have thus been detected; also, as previously instructed, the chlorine present in chlorides, and the sulphur in sulphates. Hence, referring to the list of substances abstracted from the soil by wheat, at p. 347, *ante*, it will be seen that only potassium, sodium, and phosphorus remain to be determined.

The detection of these is by no means easy by unpractised hands; first, because they are generally present in minute quantities; secondly, because of the solubility of nearly every combination of potash and soda; and, lastly, on account of the phosphorus being in combination, as phosphoric acid with lime, as the phosphate of lime.

It may be assumed, however, that the condition of potass and soda will be that of some soluble salt in the soil; and hence would be present in either the hot or cold solution recommended to be made, as *a* and *b*, at p. 382, *ante*. Two or three ounces of such a water solution, effected on 100 grains of the soil, may be evaporated in an evaporating dish to dryness. A white or yellow-white crust will thus be afforded. It may contain the carbonate and sulphate of lime, magnesia, potass, and soda; and, *possibly*, the nitrates of all of them, although such a concurrence is by no means probable—still its possibility may be looked for.

Now, in such a crust the carbonates of lime and magnesia are insoluble in water, the sulphate of lime very slightly so; whilst the sulphates of magnesia, potash, and soda, being all soluble, may be removed by the addition of a very *small* quantity of water, the effect being not to dissolve away more of the sulphate of lime than necessary. On adding water, drop by drop, it will soon be evident what part of the crust dissolves; and as soon as nothing is left but a white powder, apparently insoluble, the effected solution may be poured into a test-tube for examination.

This solution may contain sulphates of potass, soda, and magnesia, and the carbonates of the two former. By adding a minute quantity of chloride of barium in solution, all the sulphates present will be converted into chlorides, and a sulphate of baryta precipitated, that will eliminate the sulphuric acid from the solution.

If now tartaric acid in solution be added to the solution thus effected, and the sides of a test-tube containing the mixture be rubbed hard by means of a glass rod, small crystals of the bitartrate of potash will be deposited, that are highly characteristic to the practised eye. If the solution of platinum in nitro-hydrochloric acid (that is, the bichloride of platinum) be used in place of the tartaric acid, a precipitate of a yellow colour will be afforded, *insoluble* in water, and hence distinguished from the similar double salt of sodium and platinum.

The potass having thus been removed, the solution may be evaporated to dryness. A small portion of the crust produced, if put into flame, and causing a yellow colour, is a sure indication of the presence of some salt of soda, in all pro-

bability, in the soil; and certainly, by the method here produced, common salt will be evidenced as present.

Phosphoric acid, if free, may be detected with comparative ease; but, as before stated, it is almost invariably found in combination with lime, and, more rarely, with magnesia, in both of which forms it is practically insoluble. If, however, a portion of the soil be acted on, in a test-tube, by nitric acid and water, the insoluble phosphates will be decomposed, and the phosphoric acid set free. On adding a little nitrate of baryta, a white phosphate of baryta will be thrown down: but this test is valueless under such circumstances; because, if any soluble sulphate be present, then a sulphate of baryta, undistinguishable from the phosphate, would also be precipitated. A solution of nitrate of silver precipitates a yellow phosphate of silver, which can be re-dissolved in a little nitric acid; and sulphate of magnesia, with ammonia, also precipitates a phosphate—the double one of magnesia and ammonia, already referred to at p. 383, *ante*, and soluble in acids.

It requires, however, both experience and judgment to certainly distinguish potash, soda, and phosphorus, as combined with other bodies in any specimen of soils; therefore the unpractised hand cannot reckon on any results that can be relied on. It is much better, therefore, when such matters have to be determined, that the aid of a professional chemist be called in until the farmer may have acquired the necessary knowledge for such a purpose.

We have thus mentioned the leading points of a chemical analysis of a soil carried only so far as to ascertain what substances it really contains; and, of course, the instructions given have been of the most elementary nature—intended only for those who are all but ignorant of chemistry, and needless to the professional man or scientific agriculturist, who would require no instruction on any such, or more advanced matters, at our hands. The object of the preceding remarks is to induce our readers who have not yet attempted chemical analysis, to make a first start. The leading characteristics of all the substances that occur in the soil, and, consequently, in plants and animals, have already been pointed out at p. 355, and subsequent pages, together with the various peculiarities of occurrence, combination, &c., to which they are liable. The instructions just given, with the remarks there afforded, taken together by way of study, will be quite sufficient to give any person ignorant of chemical analysis a first start, and the rest must be left to intelligent, persevering practice on the part of those who would follow practically a systematic examination of the soil.

It may be useful, as a general guide, to point out an average constitution of soil for what may be called a good growing land, such as the farmer might expect to afford him a tolerably good chance of success in the growth of all the ordinary crops of the farm, as wheat, oats, barley, rye; peas, beans; clover and grass; potato, beet, turnip, mangold, &c. In giving an analysis of such a soil, however, it must be borne in mind that the constituents named are only such as may be expected naturally—say in a loamy soil—and that the different crops just mentioned each abstract substances from the soil during growth, that must be replaced by manure. Thus wheat, and the grasses generally, abstract silica to a large extent; peas, beans, clover, lucern, &c., are especially abstractors of lime; whilst beet, turnip, and potato (the last also needing lime), are notable for the amount of potash they require.

In the following table the mineral substances are grouped according to their characteristics, as alkalies, earths, &c.; and the constituents altogether form a good average soil:—

		Per cent.
Earths	Silica	58 00
	Alumina	17·00
	Lime	2·50
	Magnesia	1·00
Alkalies	Potash	2·75
	Soda	1·50
Acids	Sulphuric	0·15
	Phosphoric	0·25
Chlorine		0·50
Oxide of iron (very variable)		4·50
Organic matter, composed of oxygen, hydrogen, carbon, and nitrogen, in various compounds		9·00
Water, very variable		2·85
		100·00

In the preceding list, the actual or probable condition of each of these constituents of a soil may be considered to be generally as follows:—

Silica, alone or united with alumina as a silicate.

Alumina, with silica as above, or perhaps with iron.

Lime, as the carbonate, phosphate, and sulphate.

Magnesia, as carbonate and phosphate; rarely as sulphate.

Potash, as carbonate, sulphate, and chloride of potassium.

Soda, as carbonate, sulphate, and chloride of sodium. But if much decomposing animal matter be present, both the nitrates of potash and soda will occur.

Sulphuric Acid, as sulphates of potass, soda, lime, magnesia; and occasionally in decomposing matter, as the edges and contents of ditches, sulphur is found as sulphuretted hydrogen, already described at p. 356, in connection with hydrogen.

Phosphoric Acid is almost invariably found as phosphate of lime, or magnesia.

Chlorine occurs as chlorides of any of the earths or alkalies.

Oxide of Iron.—The sesquioxide of that metal is the only one prevalent in soils, causing their yellow or red colour.

Organic matter is extremely variable in constitution, including decomposing vegetable and animal substances, with products, such as

humus, &c., to be afterwards more particularly examined.

Water.—What has been stated in the previous table is supposed to be more or less in chemical combination. But the actual amount in any soil is as variable as the wind and weather, and dependent on both.

We thus observe that an analysis of the soil may, within certain limits, be effected without much difficulty, and so an approximate knowledge of its constitution gained. To ascertain the exact amount of each constituent present is a much more difficult undertaking, and requires several precautions to attain anything like satisfactory results, and long practice to afford them accurately.

In all cases a preliminary examination, such as we have described, should first be made, so that a general knowledge of the constitution of the soil may be arrived at; for, otherwise, an attempt to weigh each constituent would only be to grope in the dark. In the preceding instructions we have not named the blowpipe, which, with various re-agents, however, is of the utmost value in the hands of a person of some chemical experience, because he may gain all the preliminary knowledge required by acting on small quantities not bigger than a pea, or less, and obtain very satisfactory results. The limits of our space prevent our entering into the details of this method.

It may be desirable, although we are addressing those who are supposed to be ignorant of the art of chemical analysis, to mention a few points that require attention in attempting the *quantitative* analysis of a soil, in so far as its mineral substances are concerned. The operations are precisely identical with those already described, with the addition, however, of washing most carefully, drying, and weighing accurately. The following is a brief outline of such an operation :—

The soil, dried and sifted, as previously directed, should be reduced to the finest possible powder in a mortar. Twenty grains may then be weighed out, and the processes of solution and precipitation followed as already described.

First, we shall suppose the silica to be separated on the filter (see *ante*, p. 383). It must be carefully washed by pouring distilled water on to the filter, and the whole of the washings are to be added to the solution from which the silica has been separated, otherwise a portion of the substance in the twenty grains under analysis would be lost. The filter on which the silica is received should be first weighed. It is, with the silica, to be dried on a water-bath, and the amount of silica present will be that of the weight then found, less the weight of the filter.

In precisely the same way, the iron, alumina, lime, magnesia, &c., are successively precipitated, washed, dried, and weighed; and so on with each constituent of the soil that can be precipitated in a solid form.

But, after the most careful precaution and the greatest accuracy, certain calculations are necessary to arrive at the desired results, in respect to many of the constituents. The silica and alumina may be weighed as such, for they are, in a chemical condition, like that in which they exist in the soil. To a certain extent, the same holds good with the oxide of iron ; but the lime is precipitated as oxalate of that earth, and magnesia as the double phosphate. Similarly, the chlorine, sulphuric and phosphoric acids, and organic matter, all require intricate calculations, that can only be attempted with success by the thoroughly educated chemist ; and we shall therefore not burden our pages with details that would be useless to most of the readers for whose use they are intended.

The examination of the ash of plants is conducted on similar principles to those already described. The straw, or ear, is first heated to redness, to drive off all carbon, hydrogen, oxygen, and nitrogen, as volatile or unfixed constituents. Subsequently the ash is analysed, to remove in succession the silica, lime, iron, magnesia, &c. ; and thus a knowledge of the constituents of the ash, and consequently of the substances they have abstracted from the soil, is attained. As a general guide to such results, the following analysis of the leading crops of the farm is given, in respect generally to the straw, where the most considerable portion of earthy or mineral matter is found. Minute fractions are omitted, simply because a second or third analysis of the same kind of substance renders such minuteness of theoretical rather than practical value.

* *Mineral Constituents, per cent., of the ash of*

	Silica.	Alkaline Salts.	Earthy Salts.
Wheat straw . .	61·00	21·00	7.25
Oat ,, . .	62·00	34·00	4·00
Barley ,, . .	55·00	19·00	25·75
Pea ,, . .	8·00	28·00	64·00
Bean ,, . .	7·00	34·00	54·50
Clover	5·00	39·00	56·00
Turnips . . .	—	81·60	18·40
Potato . . .	—	85·80	14·00

From the above a general guide may be drawn, not only in respect to the constituents of the ashes of plants, and the substances they abstract from the soil, but also in respect to the nature of the land that should be chosen to grow the various crops there named. In this is still further evidenced the valuable character of chemical analysis to the farmer.

The analysis of manures is a subject of great practical importance to the farmer ; because, having ascertained what his land is deficient of, he naturally seeks to restore that deficiency by the addition of substances that he needs. He hence has recourse to a vast variety of natural or artificial manures to obtain his requirements.

We cannot here enter into all the details of the constitution of manures, and their individual or collective value, for a separate article must

* Extracted from *Outlines of Farming;* by R. Scott Burn, Esq.

be devoted to the consideration of so important a subject. Generally, however, the farmer mostly seeks, in purchasing an animal manure of any kind, to replace the loss of phosphates abstracted by crops from his soil, and to add such substances as afford ammonia, and, consequently, nitrogen, for the nourishment of the plant. It has long been a matter of contest as to which is the most important, the phosphate or the nitrogenous matter, especially for corn crops. Liebig and his school are highly "phosphatic" in their views, whilst another class consider that nitrogen is the essential matter. Nature provides, fortunately, for both; and thus *guano* may be considered as a manure satisfying both conditions or requirements.

But, in any case, all artificial manures are valued as containing both these constituents—phosphorus as phosphoric acid, in phosphates; and nitrogen in the condition of ammoniacal salts. As just stated, these two constituents are considered as embracing all the essential additions to soil as acted on by most kinds of crops. It rarely happens that much silica is required as an addition to the soil, for that earth is almost universally present in all soils; and where these have been created by the decomposition of felspar, potash is also generally found in sufficient abundance.

Practically, therefore, the analysis of natural and artificial manures may be considered as confined to the discovery of the phosphoric acid or nitrogen present.

We have already shown that the detection and estimation of phosphoric acid is attended with numerous difficulties. The estimation of nitrogen is only possible in the hands of a well practised manipulator. It is usually estimated as a compound, or double salt of ammonium and platinum. But various methods have been devised by Liebig, Dumas, Will and Varrentrap, with others; all complicated in their details, but each, according to the object to be obtained, specially applicable. We shall, therefore, here dismiss the subject, as one requiring greater capabilities than the majority of our readers are supposed to possess.

A few words of advice to the farmer in search of professional assistance, in respect to chemical analysis of soils, ashes of plants, and manures, may not be out of place, and may prove valuable.

There is no part of England or Scotland, from the Land's End in the former to Aberdeen in the latter, much out of reach for scientific individuals capable of giving an accurate opinion, and a correct analysis, of soils, &c., at fees amounting from one to five guineas. It would be quite out of place to mention individuals so devoting their time and talents; because, to do so would require, to a certain extent, an expression of opinion as regards individual merit. It may be generally stated, however, that any person who has been properly educated at our leading universities, in respect to chemistry—and, still more limitedly, at the public medical schools, where analytical chemistry is taught; or at the agricultural colleges, now rapidly spreading over the land—is, or ought to be, capable of giving an analysis of any soil, ash, or manure submitted to him. We are not aware that Cambridge or Oxford universities present such facilities to farmers, although the eminent professors of chemistry at each have been long favourably known for their scientific investigations. London, Bristol, Manchester, Liverpool, Glasgow, Edinburgh, &c., all have eminently practical men, whose opinion may be safely taken; and a reference to the directory of each of these cities or towns will serve to indicate individuals so employed.

The facilities of the "book-post," permit of the transmission of specimens, free from moisture, of earths, &c.; besides the quick and cheap transit provided by the railway companies. In sending specimens for analysis, the soil should be gathered from various parts of the field, as directed at p. 381, *ante*, so that it may present a fair average. It should be dried in the manner there indicated, so as not to run any risk of injury to other articles, during transit, by escape of water. All particulars of position, adjacent rocks (see Geological Conditions, p. 349, *ante, et seq.*), crops that have been grown, successfully or otherwise, should be mentioned by written statement, in all the fulness that a person would describe to his medical man the symptoms of a disease that he would be delivered from; because, as the practical chemist is the physician of the soil, &c., to the farmer, he requires an explanation of every fact bearing on the matter he has to examine.

The professional employed should be requested not only to return a tabular statement of the analysis that he has effected, but also the expression of his opinion as to the suitability of the soil for certain crops; and to suggest such manures as will supply the deficiency of the soil. In chemical analysis, it is of no use doing things by halves; for, unless all possible instructions be obtained, a partial information is more likely to do harm than good; and it is the interest of every honest professional person to give all the information he can; because the greater the success that attends the following of his advice, the larger will be the number of his clients, and, consequently, of his pecuniary profit.

CHAPTER XI.

MANAGEMENT OF SOILS, MANURES, SEWAGE—TREATMENT, ETC.

IN the early history of chemical science, we find that the alchemists kept two leading objects in view. The first was, to convert all metals into gold; and the second was, the search after some means of attaining immortality on earth. The sanguine character of each class of "philosophers" (?) presented instances in which persons boldly avowed that they had respectively succeeded in the attainment of both of those ends. But, alas for the world! time shows that there is an end to all perfection; and it is yet to be discovered how everything that glitters shall be converted into gold, and how the allotted period of threescore and ten years shall cease to become a measure of life.

It is just so in agriculture. Ever since Liebig first promulgated the only reliable basis of agricultural chemistry, previously shadowed forth by Davy, the hope has constantly been fostered, that some discovery would be made by which the farmer might grow, yearly and perpetually, the same crop on the same land; in fact, dependent on weather of course, it was expected that chemistry would present to him some marvellous compound or mixture, by which he might every year plough into the ground all that a previous crop had abstracted, and so make his fields a perpetual scene of fertility, and his granaries or barns a constantly-increasing source of wealth.

Despite all that chemistry and experience have yet done, this desirable result remains to be accomplished. It has already been pointed out, that science tells us what ought to be done—what we should replace of that which has been abstracted. In the previous pages, we have seen that a wheat or grass crop is especially greedy for silica, nitrogen, and phosphates; that peas and beans, with other leguminous plants, equally need lime; and that turnips, &c., are always taking away from the land much of the alkaline salts.

The logical inference, of course, would be, that if we knew, as we do, what the plant takes away, we consequently know what ought to be added to replace the loss. But it by no means follows, that if the right material be added as a manure, that its effects shall always equal, in practice, what theory suggests or demands. The contrary, indeed, is invariably the fact; and the reason of this will be apparent from several considerations.

On the subject of the exhaustion of soils by crops, and having pointed out that the supply of carbon from the air is inexhaustible (as already explained at p. 357, when speaking of carbonic acid gas), we quote the remarks of Dr. Anderson, of Glasgow University—one of the most eminent agricultural chemists of our time. He says:—

"In point of fact, then, the complete exhaustion of a soil in its natural state, must always be due to the want of mineral matters; because, practically, no method of treatment can deprive it of those which the air supplies. As far, also, as these matters are concerned, it must be obvious that they would rarely, if ever, be exhausted simultaneously; but that, in general, some one substance being present in relatively small proportions, the soil becomes incapable of supporting the life of plants where it is entirely withdrawn, although there may still be an abundant supply of all the others. If, for example, a soil contain a sufficient quantity of potash to yield, say twenty full crops of wheat, and of other constituents of that plant enough to yield forty crops, the excess of the latter will be unavailing, and the soil would be exhausted by twenty crops. If, now, we added to such a soil a supply of potash, it would again become capable of producing a crop; and would go on doing so until some other substance had been entirely consumed, when it also would have to be added; and so on until all being removed, the soil would, at length, end in a complete infertility, which would only be retarded, and not prevented, by this mode of operation. To maintain, during a limited series of years, a uniform amount of produce, it would be necessary to add, year by year, a quantity of the elements of plant-food equal to that which the crop removes; and the necessity for doing this is so obvious that it cannot be controverted; and it may be safely asserted, that this is a point on which all scientific and practical men agree.

"This being the principle on which the exhaustion of the soil is avoided, we have only to carry it out a little further to draw the conclusion, that, if we add to it a larger quantity of the elements of plant-food than is requisite to replace what has been removed, its productive capacity must be increased; and it will become capable of yielding a larger crop than it did in its original state. This is, in fact, the foundation of the use of manures; and if it were possible to carry out these theoretical principles in their integrity, the soil might be made to produce, during an unlimited succession of years, a crop greatly exceeding anything known in actual practice. Practically, however, there is a limit

which cannot be exceeded; and this depends on several circumstances. In the first place, the effect of a manure is not due to its composition alone, but is dependent, in no small extent, upon the different constituents existing in it, in a state in which they are readily available to the plant; and, in the second place, the composition of manures is not entirely under our control. Although farm-yard manure, which is, and will always continue to be, the foundation of agricultural practice, is a mixture containing all the elements of plant-food, and, generally, in proportions not very far removed from those in which the plant requires them; yet it is impossible not to recognise the fact, that differences occur in it, and that part of its constituents are not directly available to the plant, but only so by virtue of certain changes which occur in it after it has been deposited in the soil, and do not necessarily proceed exactly as we desire. It is a familiar fact, that, owing to these decompositions proceeding in an imperfect manner, manure may, and often does, accumulate in the soil, and remains there in an inert and dormant condition. If, from this or any other circumstances, the supply of one or more of the substances required in the plant be deficient in the manure, then either the crop is thereby limited, or it is forced to derive the requisite supply of that substance from the natural resources of the soil itself. In fact, a manure which is deficient in any one element of the crop, does not improve the soil; and though it may produce a greatly increased crop, its effect is merely temporary, and, eventually, it only causes more rapid exhaustion of the soil. In the case of farmyard manure, which necessarily contains all the elements of plants, this is, of course, less likely to occur than in special manures containing only one or two of these substances. Thus, for example, the opposite effect would be conspicuously seen in the case of a soil manured, during a series of years, with a salt of ammonia. In that case, though the crop might be greatly increased in any one year, the total amount of produce would be no larger than it would have been without that addition, but would have been obtained within a shorter period of time.

"The general conclusion to which all these considerations lead is, that we can only maintain the fertility of the soil by returning to it all the substances which the crop removes, and that we can increase it by applying these in larger quantity; but when the mixture supplied is deficient in any one substance, it does not prevent, but hastens exhaustion."

In the preceding quotation the learned professor has but briefly touched on one, and omitted mention of two other essential conditions. We refer to time, temperature, and moisture—questions that have already been discussed generally in these pages, under the head of Physical Conditions (see p. 365, *et seq.*) Now, it will be evident that these three conditions have most important influences on the value of a manure, just as, and for the same reasons that we have shown, they influence the agricultural value or condition of the soil. Thus, suppose, following Dr. Anderson's example, we adopt farmyard manure as the best of any form, it is evident that a low temperature will impede the decomposition of the vegetable, animal, and mineral matter present, decomposition being almost entirely stopped if it be laid on the land (but not in heap) in winter. On the other hand, if the heat of the sun be great, or the winds dry and easterly, the moisture necessary to carry on decomposition will be withdrawn, and the chemical changes that are essential will be impeded, if not entirely prevented, under such circumstances. Again, excess of rain-fall will carry off into the drain the greater portion of the soluble and most valuable parts of the manure, which will thus benefit the weeds in the ditch, whilst the corn in the field is starving for want of food. From both of these causes time necessarily comes in as an important question, because of their prolonging the period during which decomposition takes place, and, therefore, delaying those changes essential to the nutrition of the plant until, if effected, they become of much less value.

Our readers will thus perceive why it is that we urged so strongly, at a previous page, the necessity of not only the chemical condition of soil, &c., being kept in view, but all others to which we have alluded or described. At the present day, the application of chemistry to agriculture would have been far more advanced if a broad philosophical view had been maintained, rather than a purely chemical one; and it is only by the adoption of such a method that we can even hope, in agriculture or any other art, to reap the full benefit that science is capable of conferring on it.

Without, for the moment, entering into the chemical constitution of any kind of natural or artificial manure, we may observe, that there is much analogy between the nutritive and healthy growth of plants, physiologically, and those of animals. An animal, in a depressed condition of the nervous system, requires stimulants and tonics to restore vital energy; hence he is prescribed, if a human being, to take tinctures, quinine, &c. The land and the plant equally require such stimulus; and guano, with other stimulating manures, provide it. Hence, as Dr. Anderson remarks, ammonia will, whilst not producing a greater final total, yet afford that in a shorter time than would be required in its absence.

Bone manures are another instance of the kind. Crushed bones, spread over the land, will gradually, but for a considerable time, afford the valuable phosphoric acid; whilst the same bones converted into "superphosphate," affording the phosphoric acid more rapidly, will produce the crops quicker, and, consequently, for the time, in greater abundance. Taking these as the two extremes of manures—namely, the nitrogenous and phosphatic—all other artificial, and most other natural manures, may be similarly categorised.

From the foregoing considerations and facts, it is plainly evident that the choice and management of manures do not simply depend on their

chemical constitution, but also on a variety of other circumstances, that, whilst primarily are of less importance, collectively determine their real value. Hence it is that, whilst in one part of this country one manure answers perfectly well, in another it fails; not simply from the difference of the chemical qualities or deficiencies of the soil, but from an absence of some of the conditions that have been named as essential to due and proper applicability. We have frequently met with instances of this in various parts of our island on conversing with farmers, who have been extremely puzzled in failing to obtain the results they expected, and that were guaranteed to arise from the use of a particular manure. When these are artificially produced, especially such as are intended to be substitutes for guano, the manufacturer of them is generally blamed for having, it is supposed, an inferior article; and if its quality has been guaranteed by the written or printed analysis of an eminent chemist, still the suspicion lurks that some fraud has been perpetrated on the farmer by one or other of these individuals.

In regard to the value of rotation of crops—that is, the successive planting of crops that require different constituents for their essential nutrition—long practice, at least, seems to sanction it. One recommendation to the system is, that even if manuring be resorted to, still the element of time—so essential, as we have shown, to completely effect the chemical changes necessary—is gained. Indeed, all the arable soil of the world has been the result of a grand natural system of rotation ever since the first moss or blade of grass was produced. At first, the bare rock was absolutely incapable of producing any germination; but gradually broken up by air, moisture, heat, and frost, it produced crevices for the moss or seed to germinate in. These, decaying, afforded a richer soil, that was gradually washed into the valley below, and, accumulating, afforded a scanty subsistence for stunted grass. The decomposition of this again enriched the soil, and so gradually, in the course of ages, by great decompositions slowly progressing, it was fitted for man to till. Precisely the same thing goes on in land that is either put under rotation or fallow. The crop of the second year does not take away many of the constituents required by the crop of the first year; that of the third leaves some essential to the two foregoing. Meanwhile that portion of the soil laying dormant is undergoing constant disintegration and decomposition, and gradually preparing a fresh supply for the two crops that had been grown on it, and that will shortly again be planted on it. A constant renewal of the soil is thus kept up, provided all ordinary circumstances are favourable. Fallowing has a similar result, but is carried out under different circumstances.

There is one argument against a repeated annual growth of the same crops on a soil, which arises from the fact that all plants excrete effete matter, that acts prejudicially on others of its kind; and hence it arises that crops of all kinds become diseased if the repeated growth is persevered in. It would seem, indeed, in all forms of animate life, that alternation is beneficial. Overcrowding in our cities, intermarriages between near relations, and repeated growth of plants of the same kind on the same soil, may all be classed in the same category. It is by no means impossible, however, that means may be found by which the evil of repetitive crop-growth may be prevented. Indeed, it is stoutly maintained by many eminent chemists and agriculturists, that, by properly supplying every deficiency (caused by annual growth) through the addition of manure, any crop may be grown, year after year, on the same soil, without danger of deteriorating or exhausting it. This we doubt.

Perhaps the best argument in favour of the possible constant growth of the same crops on the soil, is drawn from such facts as have been related at p. 352, in reference to the productive power of the soils of the Nile and other river-deltas, and the extensive corn-growing plains between the Caspian and the Aral. Many parts of China would doubtless afford illustrations of the same kind. In parts of the countries first mentioned, wheat, rice, tea, and numerous other products, have been raised annually in constant succession. In America, again, cotton, sugar, and other crops are similarly produced yearly on the same soil without its having as yet shown the least signs of deterioration. But in all the places we have named there are certain circumstances connected with the presence of rich soil that must be taken into account, and that only in part occur in our climate. Thus there is abundance of heat, light, and moisture; the frequent overflow of rivers, extensive systems of natural irrigation; all of which are highly promotive of the luxuriant growth of all kinds of plants. It hence appears, that although, theoretically, chemistry may supply all the necessities of the soil in the shape of added manures, still there are limits, practically, to the adoption of that system.

At a previous page, and subsequently, the characteristics of each of the crops of temperate climes have been mentioned. They may be classified as silica crops, such as wheat, barley, and oats; lime crops, including leguminous plants, as peas, beans, &c.; and potash crops, as turnips, beet, potato, &c. The last acquire a large amount of water from the soil, varying from 82 to 92 per cent. of their total weight, and hence the solid matter they absorb bears a trifling proportion to the average weight of the crop. The lime plants, like the preceding, however, are constantly taking away constituents of the soil that are present in comparatively small proportion, and hence they require a constant renewal of lime and potash. Silica plants, on the contrary, take away an amount of their characteristic earth, which is exceedingly trifling, comparatively speaking; for whilst soil of average quantity contains between 50 and 60 per cent. of silica, potash and lime are present only to the extent of some 2 or 3 per cent. The analysis of such a soil, given at p. 384, *ante*, illustrates these facts.

The system of rotation pursued in various parts of this country varies considerably, and that with the climate. Thus, for example, in some districts barley is made to succeed turnips, clover barley, and wheat follows clover. But it is evident that such a system could only be pursued in the middle and south of England; because in Scotland, except from the middle southward, the climate is too uncertain, and the average temperature too low annually to produce anything like a good crop of wheat. In other districts two pea crops and two corn crops alternate. Indeed, no general rule can be given for rotation. It has been adopted in each district accordant with the results of experience, conjoined with the special capabilities of individual soils; and hence, to theorise on such a subject, or to suggest any general practical rule, would be impossible.

As the farmers of this country become gradually more acquainted personally with chemistry, as a pure and applied science, not only will the system of rotation be modified, but many advantages will arise that have yet been held in abeyance. In all departments of applied science, the advice, analysis, &c., of the professional man cannot be otherwise than of much value. But, however accurately he may advise, he cannot be a possessor of all the facts of the case; and the result of his investigations must, at all times when applied, partake of a general rather than of a special character, although, apparently, the opposite would seem to obtain. However, we speak advisedly here from personal knowledge, and a professional connection of a lengthened time with subjects relating to applied science.

But the man who, whilst practically engaged in a calling involving scientific knowledge, possesses that knowledge, has great advantages over him that is purely professional. Take, for example, the case of a farmer well acquainted with practical chemistry. Glancing over his fields, he will see, by the shape, size, colour, &c., of the grass, how far any chemical means he has tried have been of avail. In one part he will notice a luxuriant patch, in another a bare spot; and, using his chemical knowledge, he will sustain the richness of one, and remedy the infertility of the other. Every change in the weather, temperature, and moisture will be carefully noted; and the effects they produce will guide him, not to blind pursuit of an old system of rotation, but to the choice of a sounder and more successful one. A wet soil will be drained; a stiff one thinned; and thus each element of success in the field will be intelligently understood and improved. His stable-yard manure will not be constantly running into the drain unheeded, wasted, and lost. The physiological and chemical conditions of his cattle and dairy will be carried on, not to forcing production under this head, but rather to get all that should be got without injury to the health of the animal—a method the rejection of which, in respect to the potato and domestic ox, has led to a most serious famine of the one, and a disastrous murrain or disease in the other.

Now, these and many allied circumstances constantly passing under the eye and management of a farmer possessed of scientific knowledge, will be far more productive, individually and nationally, than could result from the advice or experiments of the merely professional chemist; for he cannot possibly go farther than suggest, whilst the other can suggest and apply.

These remarks are made as specially applicable to the choice and management of manures, on which so much has been said and written; and yet with which but moderate progress has been made. It must be admitted, however, that if we compare the condition of the subject, during the last forty years, with that of any preceding period in the agricultural history of this country, the absolute progress has been astonishing.

We next turn to consider some of the most important natural and artificial manures that have been afforded, for the use of the farmer, in accordance with the various scientific theories that have been propounded by the "nitrogen" and "phosphorus" schools of agricultural chemistry.

Guano is that which, next to the farmyard manure, has attracted much attention. As all our readers will know, it consists of the excreta of sea-birds, deposited in many islands south of the equator, and found there in immense quantities. Davy, in his lectures on "Agricultural Chemistry," in 1802—'12, mentions it as one of the most complete manures that could be obtained, containing, as it does, nearly every substance required by the farmer. According to an average, the following analysis, made by Dr. Anderson, whose opinions we have already quoted, may be taken as representing its constitution:—

Organic matter and ammoniacal salts	53·16
Phosphates	23·48
Alkaline salts	7·97
Sand	1·66
Water	13·73
	100·00

From the preceding it is evident that the chemical constitution of guano is just that which would replace the major portion of the substances abstracted from the soil by crops of temperate climates; and, consequently, its adoption during the last thirty years, in our islands, has been very extensive. Unfortunately, the great demand for it that was soon established, led to extensive adulteration and fraudulent substitution, which frequently caused not only disappointment to the farmer, but serious pecuniary loss. This circumstance, however, was not an unmixed evil; for, as already intimated, it led to the production of a vast variety of artificial manures, manufactured from substances previously of no practical use, but that now are much utilised, and of considerable value. There are many varieties of guano imported, as Peruvian, &c.; and, in one kind, a larger amount of phosphoric acid exists, the phosphates being frequently converted into

superphosphates by the addition of sulphuric acid, when this guano is sold as phospho-Peruvian. Generally all kinds of guano, although varying in quality, may be considered as the best form of forcing manure that can be employed by the farmer.

Next in value of nitrogenous manures may be reckoned animal substances of open texture or liquid, such as decomposing flesh, skin, wool, and blood. All these substances become constituents of the best kinds of artificial manures, and they have been largely used as substitutes generally for guano. Their value in nitrogen much varies; but many of them are guaranteed to be equal in that respect to guano. Such being admitted, still they rank less in value, because their nitrogenous and other substances require longer time to decompose on the land, on account of their mechanical condition, than guano, which, from its open texture or friability, is invaluable in this respect.

Besides guano, blood, flesh, &c., as artificial manures, there are numerous other substances that are an immediate source of nitrogen. Ammoniacal salts, for example, may be first noted as produced apart from animal decomposition.

The most important source of such salts is the liquor of the gas-house, to which reference has already been made at p. 348, *ante*. By the addition of sulphuric acid to the ammoniacal liquor of gas-works the sulphate of ammonia is formed.

For the information of many of our readers who may reside in the proximity of gas-works, we make the following quotation from Mr. Zerah Colburn's work on *The Gas-works of London*, in respect to the production of sulphate of ammonia from the ammoniacal liquor of coal-gas. He observes—

"In gas-making there are produced about ten gallons of ammoniacal liquor for every ton of coal carbonised [that is, distilled in the retort of the gas-house]. In some situations it has been found difficult to dispose of this liquor as a gift; and although chemists understand its value, gas engineers have not generally been so well aware of what might be made of it, so as to prevent their making long contracts for the sale of the ammoniacal liquor at very low prices. Some years ago, one of the London companies entered into a contract with a well-known chemist, who had the whole of the ammoniacal liquor for fourteen years, at 1*s.* 6*d.* per butt of 108 gallons; equal to about 1¾*d.* on every ton of coal carbonised. The purchaser, who converted the liquor into sal-ammoniac, sulphate of ammonia, &c., at an enormous profit, could have afforded to pay five shillings or more per butt; and this fact has at last become known among gas companies, of which some have taken advantage.

"If a gallon of ammoniacal liquor, of average strength, be mixed with, or saturated with about eleven ounces of sulphuric acid [oil of vitriol], and the mixture be then evaporated, about one pound of sulphate of ammonia will be obtained. The last-named substance sells for from £13 to £14 per ton to manure-makers and alum-makers; while a few years ago it brought £20. Sulphuric acid is generally more or less diluted; commercial acid, of a specific gravity of 1·728, containing 80 per cent. of absolute acid. The price is fixed upon the latter only, and is, say three farthings per pound, or about £7 per ton; and for every ton of absolute acid used, one ton and fourteen hundredweight of sulphate of ammonia, worth, say £22, may generally be made. Beyond the cost of the acid, and the slight interest upon an inexpensive plant, the cost of manufacture is practically nothing. The waste of a small non-condensing [high-pressure] engine, employed to drive the exhausters [of the gas-works], serves for evaporating the solution, and the attendance required is only occasional, and such as a stoker, or any other labourer, chiefly engaged upon other works, can easily supply."

The preceding quotation may be of much practical value to the farmer resident near a small town, where gas-works are carried on. Many of these in England and Scotland, cannot readily dispose of the ammoniacal liquor they produce; and an intelligent agriculturist, by the purchase of a carboy of sulphuric acid, and the use of two or three tubs, may produce his own sulphate of ammonia at far less than the ordinary market price.

Some persons have recommended the use of the ammoniacal liquor as obtained direct from the gas-works; but such a plan must necessarily prove highly prejudicial to the plant. In fact, on precisely the same principle, half a century or more ago, gas-tar liquor was considered an infallible specific for consumption, and numerous other diseases affecting the "flesh." He who does wisely, refrains from such use of the liquor on his land; for whatever advantage arises from the ammonia present, the addition of a vast number of heterogeneous compounds of carbon and hydrogen cannot but prove harmful.

Amongst what we may term the "slower" class of nitrogenous manures, are fresh bones, hair, horn, waste glue, woollen rags, and unrotted dung, with many other animal substances that take a considerable time to decompose. They are all valuable as affording nitrogen, carbon, and, in certain cases, phosphates. Still their action is delayed; and hence, if the farmer requires a quick forcing manure, he will choose those already named rather than such as we are now alluding to.

Nitrate of potash, nitre, or saltpetre, nitrate of soda and nitrate earth, all afford to the soil nitrogen and alkalies. They are largely used as forcing manures for grain and green crops, although much variety of opinion exists as to their value, and the quantity required, chiefly for top-dressing. Each is soluble in water; and hence a wet season, on a readily drained land, will leave little of either of them to effect much good; still, under favourable circumstances, they exercise a most beneficial stimulating influence.

Farmyard or stable-dung, with human ex-

crements, urine, &c., are a kind of staple commodity in the farm—at least the first is. In China, human excreta is considered of the highest value. It is there baked, and sold in cakes, as a regular article of commerce. It, of course, follows, that the dung of either man or animals, together with the urine, must necessarily be one of the best classes of manure for the farm, because each contains the elements that, although, as dung, &c., have been thrown away as waste, still possess every matter essential to the growth of the plant, and, consequently, of the subsequent nutrition of the animal. In fact, when the farmer puts the dung and urine of animals, human or otherwise, on his land, he returns all that has been taken away from it except the living animal and the carbonic acid produced by its respiration. These are held in fee-simple during life; but, on the death of either man or beast, when, dust to dust, they return to their origin, the earth receives her own again, and, by chemical and successive vital action, new men and new animals are created, only to undergo the same processes of life and destruction, and of themselves to become the material of fresh forms of life. The Native Guano, produced by the A B C method of treating sewage, will be described hereafter.

Cheap, yet essential, forms of manure are found in common salt; ashes of wood, that supply potash; burnt clay, which affords friable alumina; sulphate of lime; and oxide of iron; with various other substances containing potash and soda, which may, therefore, be called alkaline manures. The two most universally diffused minerals in nature, are common salt, or chloride of sodium, and oxide of iron, whether we examine the animal, vegetable, or mineral kingdoms. They are at least essential to plants and animals, not one of which has been analysed without resulting in the detection of their presence. The iron is always present in a soil; but the salt requires, in many cases, addition to it. For all members of the cabbage, turnip, and similar tribes, common salt is essential. It is an invaluable remedy, also, for conch grass; and also, in meadows, may be used as a top-dressing. It is always present in urine and excrements; but may be freely used by itself, by ploughing or harrowing, to the extent of some hundredweights per acre. Hence, in part, the value of seaweed and sea-fish as manure.

Carbonaceous manures, such as rotted leaves, dung, &c., afford to the soil one of its proximate elements, called *humus*, which is somewhat analogous to the proximate elements of plants and animals described at p. 362, *ante*, and subsequent pages; that is, it possesses the ultimate elements of carbon, hydrogen, &c., in such a form as is most suitable for, or promotive of, assimilation by the plant. Hence the great use of rotted dung, rotten leaves, peat, tan, &c., by horticulturists. And here we may, for a moment, draw attention to the value of soot, as entirely apart from the sulphate of ammonia it contains. The mechanical condition of the carbon of soot renders it extremely improbable that it is of any value directly as a manure. Indirectly, however, it has great advantages. Thus, being highly porous and attractive of gases, it absorbs such as ammonia, &c., and keeps them ready for the use of the plant. Again, it acts as a protection to the root, &c.; for, being highly antiseptic, it stops the growth of fungus, and the production of acrid or morbid matter that would act prejudicially on the fibres of the root. We have often stopped mildew by applying it freely to the stem and root, and consider it invaluable for such purposes.

Phosphate manures have, next to guano, commanded, of late years, the greatest attention, and become of the chiefest use among agriculturists in this country. In them we class "superphosphate;" burnt bones; animal black, fresh or as sent from the sugar-refiner, where it is employed to clarify or decolourise sugar; coprolites, a natural phosphate of lime, already referred to as found in the eastern portion of mid-England, as a common and extensive deposit; all kinds of guano and animal manures that contain phosphate of lime; and also, to a less degree, ashes of plants, &c., &c. We have already, at some length, entered into the question of the relative value of nitrogen and phosphorus or phosphoric acid, as a phosphate in various kinds of manures; and it will therefore be unnecessary to again venture on the discussion. Practically, the farmer may supply himself with any of these forms of phosphate by purchase. Lawes' superphosphate is an excellent form, made from coprolites as obtained from Suffolk and adjacent counties. Animal black, crushed bones, &c., may all be cheaply bought, and effectively applied. The "superphosphate" is easily made by adding sulphuric acid, or oil of vitriol of the strongest kind, diluted with twice its weight of water, to crushed bones, or coarse bone-dust. For this purpose, a wooden trough, with copper or wooden nails, may be used—not iron nails, because they would be destroyed by the acid. A slate trough may also be used. The acid and water are first mixed together, and allowed to cool. The crushed bone is then thrown in, and kept constantly stirred, so that the action of the acid may be uniform. The sulphuric acid attaches itself to a portion of the lime in the phosphate of the lime of the bones (see analysis of bone at p. 364, *ante*), and so leaves an equivalent of phosphoric acid, in one sense, free, but really in combination with lime, in a lesser proportion, as regards the earth, than had previously been the case. The following method is recommended by Mr. Sibson; but, with him, we cannot do better than advise the farmer to *buy*, rather than make, his superphosphate, taking care to go to a respectable dealer.

"For a ton of bones, which should be ground small, and boiled, to extract as much as possible of the fat, the following quantities of acid and water may be used—viz., 740 pounds, by weight, of white oil of vitriol, or 850 pounds of the brown acid; which is about equivalent to 41 gallons of the former, and 50 gallons of the latter.

"One thousand pounds, by weight, or about

100 gallons of water, are to be divided equally, one part being used to moisten the bones, and the other to dilute the acid. The latter operation should be carefully performed in a large bucket or tub,* pouring the acid in a small stream into the water, the latter being well stirred meanwhile. The bones should be thoroughly moistened with water from a garden watering-can, and left for two or three hours, or longer, to get well soaked. The mixing should be made in a wooden trough or large tub : if a sufficiently large vessel cannot be had to receive all the materials at once, it may be done in a smaller one, using successive and proportionate quantities of bone and acid ; or the mixture may be made, but not so well, on the ground (with a hard clay surface, if possible), a ring being made with ashes (black or red, about equal, in weight, to the water used), to prevent the liquid flowing away. The acid should be added gradually to the bones, the whole being stirred with a wooden rake, to ensure uniform mixture. As soon as the acid is all added, and the mixing completed, the greater part of the ashes may be thrown over the mass, and the whole allowed to stand for some days. The heap may then be opened, and the whole ashes well incorporated with it ; the mass being allowed afterwards to stand for a week or two. If not then sufficiently dry, it may be broken up again, and re-made into a heap, with a thin layer of fresh ashes. By this means a superphosphate may be got perfectly dry and manageable —the large addition of ashes being, of course, no great objection when, as we are supposing, the mixture is to be consumed on the farm where made. A superphosphate thus produced with the first quantity of ashes mentioned, was found to contain 12·27 per cent. of soluble phosphate, and nitrogen equal to 2·07 of ammonia."

The preceding plan is available in a district where bones can be obtained at a moderate cost ; but the price paid for them and the acid by the farmer render it more advantageous that the purchase of the phosphate should be adopted. Of late years, immense natural deposits of phosphate of alumina, obtained from Sombrero, in the West Indies, and similar deposits in Germany have been used in place of bones, and treated with sulphuric acid to produce a superphosphate.

Upwards of thirty years ago, we urged on one of the most eminent members of the corporation of the city of London (the late Mr. Pearson), the great value that would arise from the collection of the urine from the public conveniences in the metropolis, which, even at the present time is entirely allowed to run to waste in the sewers. At Glasgow, and some other Scottish cities, including Edinburgh, an "institution" exists that is unknown in London. It is the provision of public conveniences for another necessity of human life. From these the human excreta are collected daily, in large quantities, and sold for the use of the farmer. Many schemes have been propounded to collect such matter direct from the houses—as portable trays, filled with peat or other charcoal, fixed beneath the seat of the closet to receive the excreta. One of the most successful has been Moule's earth-closet system. No objection could exist as regards the collection of the urine from public conveniences. In the city of London alone, the ingress of men of business and others is scarcely less than 700,000 daily ; and if the total amount of "water" that, without entering into further and indelicate particulars, is thus afforded, were collected, an immense amount of ammoniacal substances would be saved. In 1,000 lbs. of human urine, according to Berzelius, there are, in round numbers, of—

	lbs.
Water	930
Urea, a most valuable source of ammonia, as pointed out at p. 734, *ante* .	30
Other ammoniacal salts and uric acid, about	20
Phosphates of soda, ammonia, lime, and magnesia	6
Sulphates of potash and soda	7
Chloride of sodium, or common salt, with the chloride of ammonium	6
Besides other matters, to the extent of about	1
	1000

Now, out of the above, there are about 70 lbs. of matter in every 1,000 lbs. of human urine, of the utmost value to the farmer. Taking 500,000 lbs. as the amount of urine produced *daily*, not in London *en masse*, but only within the *city boundaries*, we have 500 × 70, or 35,000 lbs. of the most valuable salts, &c., wasted, and cast into the Thames ; or something like 16 tons : all of which, with the accompanying liquid, might easily be collected by the simplest possible arrangements. Taking the value of the solids alone at £5 per ton (because, by other analyses, the amount of salts, &c., is less), then £80 per day, or, in the year of 300 days, £24,000 is thus annually wasted, and, to a greater or less extent, made a nuisance rather than a benefit to the city revenues. The estimate we have made is, we believe, much below than above the truth, as the physiological experience of our readers will suggest, without entering into minute details.

We must now pass from manures of a nitrogenous or phosphatic nature, or in any kind containing nitrogen or phosphorus, to others of extensive value and use, but more special in their character, and usually added with the preceding, both for mechanical and chemical purposes.

Lime manures have various uses. Mechanically, chalk, marly soil or marl, and burnt lime, serve to dilute or open out stiff clay and other heavy soils. Chemically they add lime, so essential, as we have already seen, for peas, beans, and other leguminous crops. Generally lime is largely used by the farmer. In the caustic state it is particularly valuable as neutralising the evil effects of soils loaded with

* The casks in which palm oil is imported are cheap, and useful for the purpose of making the superphosphate.

vegetable matter, in a partially decomposed state. Hence, in reclaiming peat and bog, it is of the highest service. We have already pointed out its great use in clay soils at p. 360, *ante*, in connection with our remarks on alumina and lime, and its general uses, as caustic lime, chalk or carbonate, and the sulphate, have there been also fully treated. Sulphate of lime, also known as gypsum, or plaster of Paris, in invaluable as a fixer of ammonia.

In using all the *salts* of lime, including the phosphate or bone (already fully treated on), their neutral character prevents the possibility of any injury whatever, even if applied to growing crops. It is not so, however, with caustic, or burnt lime, if fresh; for its very purpose is to *destroy* organised matter. Hence, if applied in such a condition to a growing crop, it might do a large amount of mischief. Therefore it is usual to apply it *after* the removal of a crop, and, by its action on the vegetable matter left in the soil, and the gradual absorption of carbonic acid, it becomes eventually converted into carbonate of lime or chalk, which is perfectly harmless in its action, and, at the same time, essential to all white and green crops. Wheat, barley, all grasses, clover, peas, and beans are equally benefited by lime; and it is especially valuable to turnips, &c., as preventing the disease of "finger and toe."

Amongst the miscellaneous manures not hitherto mentioned, gas-lime, or "blue billy," the refuse of the lime employed to purify gas; ashes of coal, wood, and various plants; soap-suds; road scrapings; old rags; fish; seaweed (both previously named); sulphate of iron, &c., may be ranked. They all partake, more or less, of some of the properties of the preceding; but, in all cases, are less effective. They are cheap in price, however, and easily obtained in many localities; but it would require too much space for us to detail the specific qualities of each, especially as their comparative value is generally so small.

Last, but, perhaps, as important as any, we turn to the *utilisation of the sewage of towns.*

Not to be inconsistent with previously expressed opinions, as published from our pen in some of the daily and weekly journals of London and Glasgow, it may be desirable that we should offer a few prefatory remarks.

It has always been our view, that sewage is an invaluable manure—*chemically*. But we have maintained the opinion, that, in London and Glasgow, *practically*, it is all but valueless. In 1856–'7, we entered into a lengthened discussion with a gentleman eminent in such matters, in the journals of that city; and boldly maintained, that the sewage of Glasgow, from *local causes*, was of little, if any, value. Seeing, at least once a week for six years, the meadows of Craigentinny, between Leith and Portobello, near Edinburgh, and of which we shall have to speak more fully hereafter, we had constant evidence of the value of the sewage matter. But the objection we maintained to its use was of an *engineering*, and not a chemical character. The greater portion of Edinburgh is much *above* the level of the sea, whilst *only three miles* from it; hence the sewage can readily be distributed over the meadows just referred to, simply by gravitation. In the case of Glasgow and London, such local advantages are not attainable. Both are, more or less, surrounded, within three to six miles of their centre, by hills of far greater elevation than the highest portion of each city. Hence the distribution of sewage from each must be effected by pumping it to a high level, and then allowing it to flow, by gravitation, to the places where it may prove useful. The accuracy of this fact (and we humbly submit the justice of our opinion) is affirmed by two circumstances. Twenty years have elapsed since the discussion we referred to was entered on, and the subject entertained by the authorities of Glasgow; and, up to this day, *nothing* has been done to utilise the town sewage. In respect to London, it is true that a gigantic undertaking has been *proposed.* It is, to take the sewage from the metropolis a distance of fifty miles (supplying, however, adjacent lands during its course); and, at last, to utilise it, by enclosing, or rather recovering from the sea, the Maplin sands, that have been buried beneath the water of the German Ocean, except at low tide, since the known period of our history commenced. A magnificent scheme—on paper, but futile.

With this personal explanation, to prevent the charge of inconsistency, we proceed to point out, as impartially as possible, the value of town sewage; and, for this purpose, shall largely avail ourselves of the report of the government commission, issued in 1865. Our readers will therefore be put into possession of all the most valuable facts of the case, from the authorities presumed to be the best capable of examining and reporting those facts, and, also, of suggesting their application for farming and other purposes.

The commission was appointed 5th of January, 1857, to "inquire into the best mode of distributing the sewage of towns, and applying it to beneficial and profitable uses." In their report, of 1865, the commissioners (who were the Earl of Essex, Mr. Robert Rawlinson, Professor Way, Mr. Lawes, the eminent manufacturer of artificial manures, and Dr. Simon, well known as connected with sanitary and other matters) state—"Since the date of our last report (August, 1861), we have, through a committee of our number—consisting of Mr. Lawes and Professor Way—continued, at Rugby, the experiments which were undertaken in 1861, on the application of sewage to land. * * * *

"Your lordships will observe that these experiments have not been confined to the application of sewage in different quantities to land, but have extended to the consumption, by cattle, of the produce so obtained, and to the production of meat and milk; and have been accompanied by a careful record of the quantities and market value of the products; and by numerous analyses of the sewage before and after irrigation, as also of the grass and of the milk."

After remarking, in this introduction to the report, on the amount of success that would

seem to have resulted from their labours, the commissioners add, as the result of their inquiries, carried on during eight years, and the conclusion at which they have arrived, that—

"1. The right way to dispose of town sewage, is to apply it continuously to land; and it is only by such application that the pollution of rivers can be avoided.

"2. The financial results of a continuous application of sewage to land, differ under local circumstances; first, because, in some places, irrigation can be effected by gravity, whilst in other places, more or less, pumping must be employed; secondly, because heavy soils (which, in given localities, may alone be available for the purpose) are less fit than light soils for continuous irrigation by sewage.

"3. Where local circumstances are favourable, and undue expenditure is avoided, towns may derive profit, more or less considerable, from applying their sewage in agriculture. Under opposite circumstances there may not be a balance of profit; but even in such cases, a rate in aid, required to cover any loss, need not be of large amount."

The report concludes by the suggestion—"That wherever rivers are polluted by a discharge of town sewage into them, the town may reasonably be required to desist from causing that public nuisance;" and—"That, where town populations are injured or endangered in health by a retention of cesspool matter among them, the towns may reasonably be required to provide a system of sewers for its removal."

It is thus evident, from the report, that only under favourable conditions can the sewage be made available by towns as a matter of prospective profit. Such a conclusion is precisely that which we urged years previously, and that has been already stated at p. 394, *ante*. It therefore follows, that the farmer who cannot have the sewage *laid on* for irrigating his farm, should well count the cost before he attempts to contract to fetch it. Its chemical value, laid down on his fields by a company or corporation, will be evidenced by the succeeding extracts from the report of the experiments referred to by the commissioners. What he ought pecuniarily to pay for it, must be determined—first, by the general chemical constituents; and, secondly, but most importantly, the fitness of his land to receive it; for, as the commissioners observe, "heavy soils are less fit than light soils for continuous irrigation by sewage."

The title of the report is given below,* as, perhaps, many of our readers may be desirous of procuring a copy (which, by the way, as the number that is printed is limited, may not be possible). The objects of the experiments are thus stated in the table of contents, and are of the highest importance to every farmer resident near a town. The experiments were conducted—

1. On the application of sewage to meadow land; quantities of sewage applied, and of green produce obtained.

2. On the application of sewage to Italian rye-grass.

3. On fattening oxen.

4. On the milk produced by cows.

5. The composition of the Rugby sewage.

6. The average composition of the Metropolitan sewage.

7. The composition of the drainage water of Rugby.

8. The chemical composition of unsewaged and sewaged grass.

9. The effects of sewage on the mixed herbage of meadow land in developing the more freely growing, at the expense of the less freely growing plants.

10. The composition of milk yielded from the unsewaged and sewaged grass.

11. On the application of sewage to oats.

12 and 13. Miscellaneous results of 1864 experiments; and general considerations on the agricultural utilisation of town sewage.

The conclusion is occupied with notes on the Edinburgh and Croydon sewage meadows; the sewage of towns generally; and experiments, by Dr. Stevenson Macadam, on the contamination of air and water, caused by sewage.

The extent of the report, and the great variety of its details, will necessitate, on our part, only a concise notice of its most important points—such, in fact, as are the most likely to be of value to the agriculturist to whom sewage is accessible. But, where possible, we should strongly advise to our readers the perusal of the report itself, for it contains experiments, results, tables, &c., of the highest possible value to all having any concern in such matters, whether as farmer, town councillor, or inhabitant.

We shall quote the report mostly *verbatim*, although considerable difficulty occurs in giving the exact meaning of the commissioners in few words; for a great variety of circumstances, meteorological and other conditions, rendered the details very numerous and diffuse.

1st. In respect to the *quantities of sewage applied, and the green produce afforded*, the following aggregate results were obtained on two fields:—"Taking the average results of the three years (1861, 1862, and 1863), and the two fields, we have, with sewage applied [in the neighbourhood of Rugby, where the experiments were carried on] at the rate of 3,000 tons per acre per annum, a produce per acre of a little over $22\frac{1}{4}$ tons of green grass, equal to rather more than 5 tons of hay; with 6,000 tons of sewage, rather more than $30\frac{1}{4}$ tons of green grass, equal to rather more than $5\frac{3}{4}$ tons of hay; and with 9,000 tons of sewage, rather more than $32\frac{1}{2}$ tons of green grass, equal in amount to $6\frac{1}{2}$ tons of hay.

"The largest quantities of produce reached were those obtained with the largest quantities of sewage (9,000 tons per acre per annum), and in the third year of the experiments, amounting, in the five-acre field, to 37 tons of green grass, equal to rather more than 7 tons of hay; and, in the ten-acre field, to nearly 35 tons of green

* *Third Report and Appendices of the Commission appointed to inquire into the best Mode of Distributing the Sewage of Towns, and applying it to Beneficial and Useful Purposes.*

grass, equal to nearly 6 tons 13 cwt. of hay (per acre per annum).

"The average increase of green grass over the *natural* produce, for 1,000 tons of sewage applied, was—with 3,000 tons of sewage per acre, nearly 5 tons; with 6,000 tons of sewage, rather more than 4 tons; and with 9,000 tons, not quite $3\frac{1}{4}$ tons. Reckoned as hay, the average increase for 1,000 tons of sewage was—with 3,000 tons of sewage per acre, 16 cwt.; with 6,000 tons, nearly 11 cwt.; and with 9,000 tons, $9\frac{1}{2}$ cwt." * * * * From certain local conditions varied results were produced; but "it is probable that results equal, at any rate, to those of the five-acre field, may be expected in the average of cases elsewhere; and where, as may frequently happen, a soil which yields a very small natural produce, may nevertheless, owing to its physical qualities [porosity from sand, &c.], be well adapted for the application of sewage, and give large amounts of produce per acre under its influence, the amount of increase for a given amount of sewage applied, may be even considerably higher than those obtained in the five-acre field.

"The general result is, that there was much more total produce per acre with 6,000 tons of sewage than with 3,000, and more still with 9,000; but that the increase, for a given amount of sewage applied, was less [proportionally] with 9,000 tons than with 6,000 tons, and less with 6,000 than with 3,000. The increase in the amount of produce, with each increase in the quantity of sewage applied, appears proportionally greater, when reckoned as green grass, than as hay. This is due to the much greater succulence, and, therefore, less proportion of dry substance in the more highly sewaged and heavier crops. The question arises, whether, with a less proportion of dry substance in the sewaged grass, a given weight of that dry substance will have a greater or less value, as food for stock, than an equal weight from the less succulent unsewaged grass?"

This important point will be found discussed, with the results obtained, when we notice that portion of the report in which the experiments on fattening oxen, and with milking-cows, are detailed.

2. *Experiments on the Application of Sewage to Italian Rye-grass.*—The land for these experiments was prepared for the purpose. The field, manured with farmyard dung, had produced a crop of tares, carried off in the spring of 1862. It was then cleaned, again manured with stable and farmyard dung, and sown with rye-grass in September of the same year. At the time of commencing the experiment, in the following spring, there was a promising and tolerably even crop. Owing, however, to the very small quantity of sewage available, the result of the experiments was not so satisfactory as could be desired. The ground was divided into three equal plots, one remaining unsewaged; the second had 787 tons supplied to it between April and October; and the third plot received 1,522 tons in the same period.

The total produce, per acre, was as follows, of rye-grass:—

	Tons.	Cwt.
Unsewaged	16	16
Sewaged with 787 tons . . .	20	15
Sewaged with 1,522 tons . . .	25	3

Affording, respectively, of hay—4 tons 19 cwt.; 5 tons 5 cwt; and 5 tons 12 cwt. Thus the increase of grass and hay was as follows, above that produced by the unsewaged land:—

	Grass.		Hay.	
	Tons.	Cwt.	Tons.	Cwt.
That sewaged with 787 tons	3	19	0	6
That sewaged with 1,522 tons . . .	8	7	0	13

As regards the conclusion to be drawn from the experiments, imperfect as they were, it would seem—"that there was as much, or more, increase of green produce for 1,000 tons of sewage with the rye-grass, than in most of the cases, in the same season, with the meadow grass, where so very much larger quantities of sewage were applied; though the increase of dry substance, reckoned as hay, was generally the higher wtih the meadow grass.* That is to say, the comparatively large amounts of sewage applied to meadow grass, gave, on the average, a larger amount of increase in dry or solid substance, for a given quantity of sewage, than the much smaller amounts applied to the rye-grass." Generally, the conclusion arrived at was, that the larger the quantity of sewage supplied to the rye-grass, the greater the quantity of green grass and hay afforded.

3. *Experiments with Fattening Oxen.*—The results of these experiments, when the cattle were fed on grass produced from sewage land alone, were unsatisfactory. As regards consumption of grass, it was remarked, that "a greater weight of the fresh sewaged grass was consumed per day, and per 1,000 pounds live-weight per week, than of the less succulent unsewaged grass; but the dry or solid substance contained in the larger amount of sewaged grass consumed, was less than in the unsewaged. Again, when, as in 1861, grass was given alone, more of the sewaged than the unsewaged, reckoned in the green or fresh state, was required to produce 100 pounds increase in live-weight; though the amount of dry substance contained in the sewaged grass so required, was only about four-fifths as much as that in the unsewaged grass. But when, as in 1862, a fair allowance of oil-cake was given in addition, very much less, both of fresh food and of dry or solid substance of food, was required to produce 100 pounds increase in live-weight, than, in 1861, with grass alone; and considerably less of the dry or solid substance of the more succulent sewaged, than of the drier unsewaged grass, was required.

"It is also observable that, reckoned in the

* In all these experiments, the hay equivalent in amount to the grass, is calculated by raising the amount of the experimentally determined perfectly dry or solid substance in the grass, in the proportion of from 84 to 100, on the assumption that the hay would contain 84 per cent. of dry substances, and 16 per cent. of moisture.

green state, about the same amount, both of the unsewaged and sewaged grass, was consumed per 1,000 pounds live-weight per week, in 1862, with oil-cake in addition, as in 1861 with grass alone ; but the dry substance supplied in the grass consumed in 1862, with oil-cake, was, both with the unsewaged and the sewaged grass, less than in 1861 without it. * * * * In 1862, the rate of increase, per 1,000 pounds live-weight per week (if taken over the whole period of the experiment of nearly twenty-three weeks), was, both with unsewaged and sewaged grass (with oil-cake in addition), about equal to the average obtained with animals, of fair quality, fed on good fattening food ; but the food consumed for the production of 100 pounds of increase, even in the case of sewaged grass, contained more dry or solid substance than is usually required when oxen are liberally fed on oil-cake, hay-chaff, and roots ; and with the unsewaged grass considerably more. It should be borne in mind, however, that the experiment with unsewaged grass was on two animals only, whilst that with the sewaged was on eight ; giving, therefore, a much more trustworthy average.

* * * * * *

"By the aid of sewage, the time which an acre of land would provide food for an ox, was increased three or more fold, varying according to the amount of sewage employed. Taking into account, however, the large amounts of oil-cake consumed, with the produce of each acre in 1862, it results that (with one exception in the experiments) a given area would support considerably less stock, in the cold and wet season of 1862, than in the more genial one of 1861.

"The amount of increase in live-weight yielded from the produce of an acre, was also increased several fold by means of sewage ; about threefold with the highest amount of sewage when the grass was consumed alone, and nearly fourfold when oil-cake was given in addition, in much about the same proportion to a given amount of the unsewaged and sewaged grasses."

When the sewaged grass was consumed alone, the increase of live-weight was very small. But when the sewaged grass and oil-cake were given together, the money return per acre was from three to four times greater with the sewage than without it. The increased value diminished with an increase of the sewage, not absolutely, but relatively, with an increased supply of sewage. Thus, although the money return would be greater where 9,000 or 6,000, than where only 3,000, tons were applied per acre, yet the return calculated, not per acre, but for each 1,000 tons of sewage, was in each case the less the greater the amount of sewage applied.

The commissioners came to the conclusion, that milk returns a much higher money value than meat for the same amount of sewage, although successful results have been obtained in fattening on sewaged grass, &c., at Croydon. There the land was irrigated with sewage for three or four days and nights together, two or three times for each crop ; and when the grass had got a sufficient head, they stopped the application, and turned the stock upon the land, there to remain until the grass was closely eaten down. The cattle were then removed, and irrigation was had resort to as before.

It is impossible to transcribe here the extended tables afforded in the report ; and, therefore, we must refer our readers to it for full information of results in quantities, the amount of sewaged and unsewaged grass consumed, also of oil-cake, &c., &c. The following table, however, gives some important particulars :—

Amount of Food Consumed (Unsewaged and Sewaged Grass, with or without Oil-cake), to produce 100 *pounds weight increase in Live-stock.*

Sixteen weeks in 1861.	Grass in Pounds.	Oil-cake in Pounds.
Unsewaged grass . . .	23,669	——
Sewaged grass . . .	24,735	——
Eighteen weeks in 1862.		
Unsewaged grass . . .	8,489	310
Sewaged grass . . .	9,115	273

The increase in weight per week, in 1861, for every 1,000 pounds of live-weight, was 2 pounds 7 ounces with unsewaged, and 2 pounds 11 ounces with sewaged grass.

In 1862, when oil-cake was used with both grasses, the increased weight per week, for every 1,000 pounds of live-weight, was 6 pounds 5 ounces on unsewaged grass and cake, and 7 pounds 4 ounces on sewaged grass with cake. This at once shows the value of the addition of the cake in either case, and the special value of the sewaged grass under the same circumstances.

It was calculated that one ox might be kept fed with oil-cake, on unsewaged grass, for twenty-six weeks per acre. But the sewaged grass, with oil-cake, would support one ox, per acre, for from seventy-two to eighty-four weeks —evidencing the highly stimulating effect which the sewage has in respect to the production of meadow grass.

The increased value of each 1,000 tons of sewage, with oil-cake, varied in different experiments from 21*s.* to 52*s.*; and, without oil-cake, from 13*s.* 8*d.* to 33*s.* These facts have been extracted from Table VI. in the body of the report ; but in the appendix, all the details of each experiment are given ; the above table being merely a summary of them.

4. *Experiments with Milking-Cows.*—In respect to dairy farming, now so extensively carried on in most parts of the kingdom, the experiments carried out by the commissioners, to test the value of sewaged grass for milking-cows, are of the highest importance, and most satisfactory in their result. We have seen that no great value is attached to the sewaged grass in its use for fattening animals, in which operation the production of solid matter in the animal is only sought for. In the production of milk, a contrary condition prevails, for then, of course, the fluid secreted by the animal is chiefly desired ; and it follows, that a succulent food, such as sewaged grass supplies, must necessarily prove of essential service.

The experiments were carried on, in three successive years, at Rugby. In 1861, twelve selected cows were set to feed on grass alone, two on unsewaged, and ten on sewaged grass, for a period of sixteen weeks. At the expiration of that time, the experiment was continued four weeks longer, with an allowance of oil-cake.

In 1862, three cows were selected to receive oil-cake and unsewaged grass; and twelve were supplied with sewaged grass and oil-cake, the experiment being carried on for twenty-four weeks.

In 1863, twenty recently calved cows were selected, five for unsewaged meadow grass, ten for sewaged meadow grass, and five on Italian rye-grass. The intention was to give each lot grass alone for the first twelve weeks, and afterwards grass with oil-cake.

The results of the experiments varied from several causes. "Represented in quantity of milk, in 1861, when the sewage was not applied until the spring, the produce per acre was, without sewage, 321½ gallons, and, with the different amounts of sewage (3,000, 6,000, and 9,000 tons annually per acre), 570¾, 820½, and 961¼ gallons of milk were afforded. Reckoned according to the rate of consumption of grass, and of the yield of milk during the first twelve weeks, or most favourable period of the grass season of 1863, when, as in 1861, the grass was consumed alone, but, unlike 1861, the sewage had been applied throughout the winter months, and when the cows, being mostly newly calved, were also in their most favourable condition, the estimated yield of milk, reckoned upon the total produce of grass per acre, was—without sewage, 402 gallons; and, with the different amounts of sewage, 1,019, 1,404¾, and 1,544 gallons respectively; or so far as the sewaged plots were concerned, from one-half to two-thirds more per acre than in 1861, reckoned according to the rates of consumption and yield of milk over the whole of that season.

"With the aid of large quantities of oil-cake, the yield of milk in 1862—when the season was very favourable for the unsewaged, but comparatively unfavourable for the sewaged land—was—without sewage, 666½ gallons; and with the different amounts of sewage, 920½, 1,072¾, and 1,056 gallons; and according to the rates of consumption and yield of milk when oil-cake was given during the latter half of the season of 1863, the yield of milk per acre, calculated upon the total produce of grass throughout the season, in each case, was—without sewage, 444¼ gallons; and with the different amounts of sewage respectively, 780, 1,075, and 1,181½ gallons respectively. * * * * So far as may be judged from the limited experience which these results record, it would appear probable that, with an average supply of about 5,000 tons per acre per annum of sewage to meadow land, and with cows taken indiscriminately at various periods after calving, an average of not less than 1,000 gallons of milk per acre might be expected; or more than this when cows are taken at their best, and the season and other circumstances are more than usually favourable."

The experiments with the Italian rye-grass were of too limited a nature, being for one season only; but it is stated, that with this grass, "a larger yield of milk per acre may be obtained, for the application of a given amount of sewage, than with meadow grass. But with Italian rye-grass the land has to be periodically broken up, during which time less sewage per acre, if any, can be utilised; and hence, for the distribution of a given amount of sewage, the expense of laying down a much larger area would be necessary, so far as this crop was introduced.

"The results, taken as a whole, lead to the conclusion, that the gross return of money per acre, reckoned in milk at 8*d.* per gallon, might be estimated at certainly not less than £30 to £35, with an application of about 5,000 tons of sewage per acre per annum. * * * * *

"It may be observed, that so far as these results give the means of judging, it would appear that an average of about £5 increased value of milk, reckoned at 8*d.* per gallon, may be anticipated from the application of each 1,000 tons of sewage, when the amount applied does not exceed 5,000 tons per acre per annum. This would be equivalent to a *gross* value of increased produce of milk, of rather more than *one penny per ton* of sewage applied."

It will be evident, therefore, that for cows in milk in connection with the dairy farm, the application of sewage is of great value. We cannot go into further statistics of these matters; and sufficient has been said to show the great increase of production that evidently arises from the application of sewage to either meadow or rye-grass. The actual quantity of grass eaten by the animals, is greater of the sewaged than the unsewaged; but as the former is so much more largely produced on the same area of ground, and is attended with such an increased production of milk, of course the sewaged grass must prove of the highest value to the dairy farmer. The following particulars, in respect to these experiments, will be of interest in connection with this department of our subject:—

Season 1863.—*Meadow Grass only.*

	Consumption per head per day, of grass in pounds.
Unsewaged	99·1
Sewaged	142·9

	Per 1,000 lbs. of live-weight per week, pounds.
Unsewaged	650
Sewaged	963

In the preparation of this and the following table, the calculations are not based upon the results obtained during the whole of the "periods" of experiment; those obtained during any part of a "period," when, for want of a sufficient supply, the animals received any other than the proper description of grass, being, as far as possible, excluded. The exceptions so made relate chiefly to the experiments with unsewaged grass, the supply of which was not

so regular, throughout the seasons, as of the sewaged.

During the same period, the consumption of Italian rye-grass alone was, per day per head, 159·3 pounds, or 10·36 pounds per 1,000 pounds of live-weight per week. With meadow grass and oil-cake, the consumption per head per day was—

	Grass. In Pounds.	Oil-cake.
Unsewaged	95·4	1·7
Sewaged	157·4	1·8

And for 1,000 pounds of live-weight per week—

Unsewaged	61·6	10·8
Sewaged	104·1	12·1

With Italian rye-grass and oil-cake, the consumption per head daily was—

Unsewaged / Sewaged	142·5	1·5

And for 1,000 pounds live-weight per week—

Unsewaged / Sewaged	92·9	9·6

The commissioners, in the report, next proceed to consider the composition of sewage, &c.; and so occupy from No. 5 to No. 9 of the headings given, *in extenso*, at p. 395, *ante*. But it will best answer our purpose to carry on the inquiry as regards the milk at this portion of the work, and then continue the question generally. We shall, therefore, next consider—

10. *The composition of the milk yielded from the unsewaged and sewaged grass*, because this is of primary importance; for, if an increased quantity be afforded by sewaged grass, attended with any diminution of quality, all advantage may cease to arise from the use of the sewage.

Without entering into the details of all the experiments, once a week during the greater part of the season of 1861, the morning and evening milk of the cows fed on unsewaged grass was mixed together, and a gallon sample taken. Samples of milk from the sewaged grass were taken in the same way. In 1862 similar samples were collected, but then only once a month. In 1863 none were taken. In all these cases, the samples were, as soon as taken, put into bottles, filled up to the corks, sealed down, and sent off on the same evening, by railway, by Professor Way, to analyse. The results, summarised in the report, are as follows :—

"The general result is, that a given weight of fresh unsewaged grass, supplying, as it did, much more solid matter, gave more milk than an equal weight of the fresh sewaged grass; that a given amount of the dry or solid substance of the more succulent sewage grass, gave considerably more milk than an equal quantity of that of the unsewaged; that the addition of oil-cake, whether to unsewaged or sewaged grass, increased the richness of the milk; but that the milk from the sewaged grass (whether given alone or with oil-cake), was somewhat less rich than that from the unsewaged."

The following tables are the results of the analysis of milk produced, in 1862, with meadow grass and oil-cake together, as food for the cows; and the results are a mean of six analyses :—

	Grass and Unsewaged.	Oil-cake. Sewaged.
Caseine	3·513	3·467
Butter	3·834	3·559
Sugar of milk, &c.	4·502	4·440
Mineral matter	0·753	0·771
Total solid matter	12·602	12·237
Water	87·398	87·763
	100·000	100·000

From which it will be perceived, that the caseine or cheese, the butter, and sugar are all less from the sewaged than from the unsewaged; whilst the mineral matter is greater, as is also the water, in the sewaged grass milk.

The total difference, however, is very trifling. Thus, in every 100 pounds, or ten gallons, of milk, there would only be one-third of a pound, or the $\frac{1}{300}$th part less of solid matter in the sewaged than in the unsewaged; and, taking each of the solids separately, it barely reaches that deficiency in the butter, and is very much less than that in the caseine or cheese. Now, when we note this deficiency as, on an average, showing a worse quality of one part in three hundred, and turn back to p. 398, *ante*, where will be seen that the amount of milk is more than doubled or trebled by the sewage, such a deterioration is too trifling to be of the most remote importance. In fact, its ratio, with the increased supply, is too minute to be of the least fractional pecuniary value.

We next turn to a question of great importance, involved in four of the headings of the report (see *ante*, p. 395)—namely :—(5) *The Composition of the Rugby Sewage;* (6) *That of the Metropolitan Sewage;* (7) *The Composition of the Drainage Water of Rugby:* and (8) *The Chemical Composition of the Unsewaged and Sewaged Grasses.*

The whole of these headings treating on similar and allied substances, we shall pass them in review together, in respect to their absolute and relative purposes; referring the reader generally to our remarks on the chemical analysis of soils, &c., given at length at p. 378, and following pages, as a generally assistant guide for those readers who are not acquainted with the subject.

The number of analyses undertaken was, of course, great; and the results were varied. In some of the years, and between the years, respectively, 1861, 1862, and 1863, the quantities of suspended and dissolved matter, both organic and inorganic, fluctuated. The quality also varied between the five-acre and the ten-acre field, the latter being poorer in every respect; that is, containing most water, and less organic and inorganic matter. The following results of the analysis, which is a mean of ninety-three

samples, we have selected from Table VIII. of the report.

Average Composition of the Rugby Sewage in One Imperial Gallon.

		Grains.
Organic matter	In solution	8·63
	In suspension	18·85
	Total	27·48
Inorganic matter	In solution	35·81
	In suspension	24·30
	Total	60·11
Total in solution		44·44
Total in suspension		43·15
Total solid matter		87·59
Ammonia	In solution	4·89
	In suspension	1·60
	Total	6·49

Taking 1,000 tons of the sewage, a mean average of its constitution is as follows:—Of organic matter in suspension and solution there was 879·4 lbs.; of inorganic, suspended and in solution, 1,923·5 lbs.; and of ammonia, in suspension and solution, 207·7 lbs.

We have already alluded to the great variation that occurs in the composition of the sewage. The report affords a table of analyses, made at various periods, to test the quantity of ammonia present. It will be unnecessary for us to reproduce them, as the following remarks will sufficiently elucidate the subject:—

"The amount of ammonia which, to such a great extent, rules the estimated value of the sewage, varied at different times during thirty-one months, from about 2½ to about 15½ grains per gallon, or from 81½ to 500½ lbs. per 1,000 tons; and the total solid matter varied from about 37½ to about 270 grains per gallon, or from 1,203 to 8,637 lbs. per 1,000 tons. It will be obvious, from these results, how valueless for the purposes of determining the average composition of the sewage of any locality—indeed, how utterly misleading—must be the analyses of samples taken without due regard to the circumstances by which its composition is so materially affected."

On an average of thirty-one months' analysis, the conclusion is arrived at, that the Rugby sewage consists of—

	Grains per Gallon.	Pounds per 1,000 Tons.
Total solid matter	92·5	2,960
Ammonia	7·0	224

The next conclusion is one of high importance, in respect to the money value of sewage, compared with other manures. We give it entire:—

"Assuming this [the previous table] to represent the average composition of the Rugby sewage during the period in question [thirty-one months], 1,000 tons may be estimated to contain nitrogen, reckoned as ammonia, equivalent to that contributed in the mixed excrements, and associated matters of between seventeen and eighteen persons of a mixed population, of both sexes and all ages, in a year, or to that in between eleven and twelve cwts. of Peruvian guano. In other words, about 1,700 tons of sewage would contain nitrogen, reckoned as ammonia, equal to that of one ton of Peruvian guano. Yet it has been seen that the increase of grass obtained by the use of 1,000 tons of this sewage did not, under the most favourable circumstances, exceed that which would correspond to about twenty-six cwts. of hay; and was, on the average, much less."

Qualifying the preceding estimate, a note is added to the report:—"The rain-fall of the period of the experiments, and, therefore, the dilution of the sewage, was, however, less than the average; according to which it is estimated, that, with the present arrangements, 1,000 tons would represent the excretal matter of scarcely seventeen average individuals, and the ammonia of scarcely eleven cwts. of Peruvian guano."

In respect to the phosphoric acid and potass present in the sewage, and a point of great importance in its value—for Liebig considers that the addition of phosphates would render sewage invaluable—the Rugby sewage presented great variations. Thus, from April, 1861, to July, 1864, in one gallon, the amount of phosphoric acid varied from 3·12 grains to 0·64, and the potass from 4·95 to 0·61 grains. It was found that there was generally a relation between the quantities of these and that of ammonia present; and that when the sewage was rich in ammonia, it was also so in phosphoric acid and potash. Similarly, when the ammonia was deficient, the other constituents were also in proportional less quantity.

The average of the whole period, from April 1st, 1861, to July 18th, 1864, was as follows:—

	Grains in one Gallon.
Ammonia	7·51
Phosphoric acid	1·68
Potash	2·81
Average proportion to *one* of nitrogen was, of—	
Phosphoric acid	0·27
Potash	0·42

Whilst the ammonia is chiefly in solution, and the potash always so, the phosphoric acid is generally in suspension, mostly as phosphate of lime. The variations of the phosphoric acid depend on that of the animal excreta; whilst a considerable proportion of the potash is derived from the washings of the streets down the drains, the potass being obtained from the granite and other volcanic material, of which the pavement and roadway are made. Granite, felspar, &c., are, in part, constituted of potash, as already pointed out at p. 358, *ante*.

A question of importance arises, therefore, from the preceding analyses. It is that of how far sewage matter can supply the requirements of various kinds of crops that it may be attempted to grow by its use? The preceding tables, &c., show what sewage contains on an average. It is desirable, however, to ascertain what each crop requires in respect to ammonia, phosphoric acid, and potash.

The following tables give an average of such requirements. They show how much each kind of crop requires of phosphoric acid and potash, when it needs *one* of nitrogen. Thus, if wheat requires 1 of nitrogen, then, according to the tables, it will require in root, straw, &c., 0·46 of phosphoric acid, and 0·57 of potash.

Proportion to 1 *of Nitrogen of Phosphoric Acid.*

	In Corn, Roots, &c.	In Straw, Leaves, &c.	In total of Plant.
Wheat	0·48	0·42	0·46
Barley	0·40	0·34	0·38
Oats	0·28	0·37	0·30
Meadow hay. . .	—	—	0·27
Clover hay . . .	—	—	0·23
Beans	0·25	0·46	0·30
Mangolds . . .	0·17	—	—
Swedes	0·27	0·16	0·21
Common turnips .	0·28	0·18	0·26
Potatoes	0·42	—	—

The following table affords a similar value required of potash :—

	In Corn, Roots, &c.	In Straw, Leaves, &c.	In total of Plant.
Wheat	0·28	1·08	0·57
Barley	0·34	1·26	0·60
Oats	0·25	1·55	0·65
Meadow hay . .	—	—	1·00
Clover hay . . .	—	—	0·52
Beans	0·32	1·23	0·50
Mangolds . . .	1·00	—	—
Swedes	0·82	0·44	0·63
Common turnips .	1·60	0·71	1·17
Potatoes	1·23	—	—

The following observations will reduce the preceding tables to their due practical value, in respect to the general use of sewage :—

"According to these figures, if, on the application of sewage to meadow land, the whole of the nitrogen supplied were recovered in the increase of produce, it is obvious that there would be associated with it, in the manure, almost exactly the amount of phosphoric acid, but less than half the amount of potash required by the crop. But, in practice, considerably less nitrogen is recovered in the increase of the crop, than is supplied in the manure employed to produce it. Then, again, the dry or solid substance of sewage grass, as it is generally cut, contains a considerably higher per-centage of nitrogen than that of ordinary meadow grass as cut for hay; whilst from the results of direct experiments made on the point, it is probable that the proportion of phosphoric acid to 1 of nitrogen, is somewhat lower, and that of potash somewhat higher, in sewaged grass than in ordinary meadow hay. It follows that, if the relation of phosphoric acid and potash to the nitrogen in sewage be fairly represented by the average results of the few analyses given on the point, it would contain more phosphoric acid, though, perhaps, not so much potash, as could be turned to the account of growth under the influence of the amount of nitrogen at the same time supplied.

"Of phosphoric acid, at any rate, there would probably be an accumulation within the soil, rather than an exhaustion of it, by the use of sewage to grass land. Still, agricultural experience shows that an apparently excessive supply of phosphoric acid is frequently useful in giving a favourable development or tendency of growth in a plant; and, in this way, it is possible that the application of phosphatic manures, in conjunction with sewage, might be advantageous. As above stated, the proportion of the potash to the nitrogen in town sewage, would vary considerably according to the locality; and where there was no other source of it than food refuse, and the excretal matter of man and animals, it would be more likely than the phosphoric acid to be in relative defect, in case of the constant application of the sewage to grass land. In corn crops, such as wheat or barley, the proportion of phosphoric acid to nitrogen is much higher also than was found in the Rugby sewage. The average proportion in the sewage was, however, not deficient, compared with that of the phosphoric acid in these crops, to the amount of nitrogen which, in common practice, is required to be supplied in manure to yield one of nitrogen, in the form of increased produce. Of potass, the proportion to 1 of nitrogen in these crops is, in the grain, which alone is generally sold off the farm, considerably less than was found, on the average, in the Rugby sewage. In fact, if town sewage were used on any comprehensive scale to corn crops, grown in rotation, phosphoric acid would be more likely to become deficient than potash in ordinary soils; but if phosphatic manures were employed for other crops of the course, they would not need to be supplemented to the sewage of corn. It is, indeed, even known that phosphatic manures are, in practice, much more used, and are much more effective, for root than for corn crops; yet, as the tables show, the proportion of phosphoric acid to 1 of nitrogen, is lower in the root than in the corn crops."

The general conclusion to which this portion of our subject arrives is, that potass would be more likely than phosphoric acid to become deficient where town sewage was applied constantly to meadow land; whilst phosphoric acid would be more likely to become deficient than potash, where it was applied to the ordinary crops of rotation.

The importance of the sewage of the metropolis is so great, and has become almost of

European reputation, that we shall not take it in the order adopted by the commissioners, but leave it for the present, for the purpose of briefly alluding to the *drainage* water of Rugby, and afterwards deal with the metropolitan sewage to a considerable extent.

In reference to the composition of the drainage water of Rugby, the experiments made were intended to determine—

First. To what extent the sewage is deprived of its manurial or putrescent constituents in its passage over and through the land. And—

Secondly. Whether the sewaged land is left in a higher or lower condition after the removal of the crop.

To gain some information in reference to the second of these points, it was decided that, during the season of 1864, the produce of each plot should be carefully weighed, sampled, and analysed, without any further application of sewage; and that the soil of each plot should be submitted to such chemical examination as time and other circumstances would permit.

Numerous results are tabulated in the report of the commissioners, to which we must refer our readers for full information. To make the results as accurate as possible, the sewage water, before falling on the land, and the drainage water resulting from its passage, were collected simultaneously, and submitted to analysis. The results showed that, "of the matter in suspension, nearly the whole, both organic and inorganic, was separated from the sewage in its passage over and through the land; the drainage water containing but little of either; and probably a considerable part of that which it did contain was not contributed by the sewage, but was derived from the soil itself. The following table gives the results of the comparative analysis of both sewage and drainage water, from November, 1862, to October, 1863, both inclusive, of the two fields at Rugby, in grains per imperial gallon:—

		Sewage Water.	Drainage Water.
Substances in solution	organic	8·32	7·73
	inorganic	39·18	39·98
	Total	47·50	47·71
Substances in suspension	organic	26·69	2·37
	inorganic	37·22	3·06
	Total	63·91	5·43
Total organic matter		35·01	10·10
Total inorganic matter		76·40	43·04
		111·41	53·14
Ammonia	in solution	5·76	1·28
	in suspension	2·03	0·23
		7·79	1·51

The results were obtained from the comparatively level five-acre field, and the steeply-sloping ten-acre field over which the fluid sewage passed more rapidly. In another portion of the same table from which we have made the preceding extract, there was 7 per cent. of solid matter passed into drainage from the ten-acre field more than that which escaped from the level five-acre field; whilst the ammonia passed off into drainage was two-and-a-half times greater in the sloping ten-acre field than in the level five-acre field. Thus it is evident that the level field will retain more of the valuable matters of the sewage than one which is inclined downwards from the point at which the sewage enters it. We again remind our readers of the importance of physical conditions in agriculture as being of little less value than those of a chemical nature; and a careful perusal of the following results of analysis will evidence the value of a due consideration of them. The following table is a valuable analysis of the sewage and drainage water collected at Rugby, in July, 1864, in grains per imperial gallon of both:—

Matter in Solution.

Inorganic.	Sewage.	Drainage.
Oxide of iron	1·25	0·25
Lime	8·23	10·08
Magnesia	1·80	1·69
Soda (1)	5·24	2·30
Chloride of sodium (1)	8·53	9·21
Chloride of potassium (1)	6·17	2·34
Sulphuric acid	4·01	6·75
Phosphoric acid	1·66	0·32
Carbonic acid	7.42	7·01
Silica	1·00	0·80
	45·31	40·75
Organic matter in solution	10·00	7·05
Total matter in solution	55·31	47·80

The next constituent to be noticed, of both sewage and drainage, is that held in suspension, which was as follows:—

Matter in Suspension.

Inorganic.	Sewage.	Drainage.
Oxide of iron, and alumina	6·30	—
Lime	3·75	—
Magnesia	0·25	—
Carbonic acid	2·17	—
Phosphoric acid	1·14	—
Silica, sand, &c.	39·30	—
	52.91	—
Organic matter	32·40	—
	85·31	—
Total organic matter	98·22	40·75
Total organic matter (2)	42·40	7·05
Total solid matter	140·62	47·80

Two references are made in the preceding tables of analyses, marked respectively (1) and (2). They refer to the alkaline and nitrogenous

matter (as ammonia), and are thus explained. The fixed alkaline matters marked (1) are :—

	Sewage.	Drainage.
Potash	3·90	1·48
Soda	9·76	7·17
Chlorine	8.10	6.70

The reference marked (2) refers to the ammonia, the quantities of which were as follows :—

		Sewage.	Drainage.
Ammonia	in solution	6·36	0·92
	in suspension	2·42	—
	Total	8·78	0·92

The nitric acid in solution in drainage water, represented in value 1·162 of nitrogen, or 1·411 of ammonia.

From these elaborate, although summarised statements of analysis, the agriculturist acquainted with chemical analysis must obtain information of the highest practical value. He is supplied with nearly every particular that is of importance to him in the utilisation of town sewage ; and it will be for him to judge how far he can prudently avail himself of its use; and be encouraged to aid town councils or other officials in bringing to the farm products evidently of much value, although requiring great discretion in their adaptation, solely or combined with other manures, to the growth of various crops.

In the preceding analyses nearly all the inorganic matters in suspension are seen to be retained by the soil from the sewage ; and so great was this absorption that it was not thought necessary to take notice of any that passed off, especially as it was thought that the trifling amount that did pass off was really derived from the soil itself, and not from the sewage. The difference between the inorganic constituents of the sewage and drainage is so slight, as evidently to prove that a greater proportion was retained than was cast off. It will be evident, that both in respect to the phosphoric acid and potash, more was retained than passed off. In respect to the ammonia, the retention was remarkable—8·78 grains passing in with the sewage, and only 0·92 being lost by the drainage. At the same time it must be noticed, that while no traces of nitric acid (consisting of one of nitrogen to five of oxygen) occurred in the sewage, still, in the drainage, an amount equivalent to 1·41 grains of ammonia was discovered. But this is not a matter to cause surprise : whenever nitrogen, lime, oxygen, &c., meet together, an oxidating action goes on, and, taking advantage of this, in some countries, nitre or saltpetre (the nitrate of potash) is formed artificially, by heaping mortar, animal matter, &c., together, adding a salt of potash, and afterwards dissolving out the nitre, which forms in such a heap, just as it does in sewage laid over or irrigating a field.

On this and the passage of potass, &c., the following remarks are made :—"The amounts of potash, phosphoric acid, ammonia, and nitric acid, found in the drainage water, clearly show that the sewage was not perfectly deprived of its valuable manurial matters in its passage through the soil ; and the amounts of total soluble matter, and especially of soluble organic matter, show that it was by no means perfectly purified. There is, indeed, a limit, depending upon the physical and chemical characters of the soil, and upon the amount and composition of the fluid passed through it, to the power which a soil possesses of removing substances from solution, or of preventing those already absorbed from being dissolved in water passing through it ; and so far as the soluble organic matters of the drainage are derived from vegetable matter within the soil, it is a question whether there will not always be a considerable amount in that passing from land covered with a luxuriant vegetation. So far, however, as the nitrogen of the drainage exists in the form of nitric acid, it is a pretty satisfactory indication that the organic matter has, to a great extent, already passed the stage of deleterious putrefaction."

But the incomplete absorption of any or all of the constituents that have been mentioned as passing through into drainage, may be remedied by passing the drainage water over the land once or twice. By such means a larger proportion of the valuable products of the sewage would be retained ; and not only so, the refuse drainage water would be so far purified that it might be safely passed into rivers without any risk of harmful pollution of their waters. This has already been effected so far at Croydon, that, whilst at one time the Board of Health at that town had to defend several actions for pollution of the river by sewage, the drain-water is now so purified as to be actually sought for by the fish.

We now turn to a matter of great importance in considering the—

6. *Estimated Average Composition of the Metropolitan Sewage.*—There is, perhaps, no subject in Applied Chemistry that has created more lively discussion, and has called forth more divided opinions from some of the most eminent European chemists—as Liebig, Hofmann, Witt, Way, &c., than this. The subject, in fact, is one of such difficulty and uncertainty that we approach it with great hesitation, not only because of the diversity of the opinions that have been expressed in regard to its utility and value, but also because it is impossible to arrive at anything like a just conclusion, simply on account of the data on which that could be formed being variable and uncertain.

The recent and present, or, perhaps, more correctly, progressive conditions of the drainage introduce elements of discordance. Formerly, the whole of the metropolis, from Highgate to Norwood, and Kew to almost any reasonable distance below London Bridge, was drained by a variety of small sewers, every one receiving sewage of a character more or less dependent on the occupation of the inhabitants through which it passed. Consequently, if one district was chiefly occupied with private houses, its sewage would naturally be an average of what sewage should be ; that is, a composition of the animal

and vegetable excreta or waste of private houses, with the wash, cooking, and other domestic waste waters. But in another district a number of factories may occur; hence a large quantity of miscellaneous waste matter, solid and liquid, together, perhaps, with a large amount of water used in the process of manufacture, would pass off into the sewer, and introduce elements of analysis that would be of the most perplexing nature, if we attempted to draw from them anything like accurate conclusions.

We write this with an experience, more or less, of a forty-five years' residence on the *north* side of the Thames. But, during a portion of that time, some experience on the southern side leads us to the belief that there the conditions are still more complicated. For example, we could point out a well in Walworth, only eight feet deep, the water of which was so loaded with saline matter, as to line a 20-horse power steam boiler with as much "fur" of lime and oxide of iron as would fill a brick-cart with a standard "load," monthly, on being cleaned out. Again, there are, on the south of London, the refuse of extensive tanneries, a low population, many factories engaged in matters containing animal substances, with other perplexing conditions too numerous to mention.

So far we have recounted what may be called the *was* of London drainage; and numerous analyses were made of the discharge of sewers into the river, or before the sewage water reached the stream, giving results of a highly discordant character, and affording equally encouragement to the sanguine practical chemist, and discouragement to him of more cautious or phlegmatic temperament.

Now, however, an entirely new system of things has been introduced. By the splendid system of the main drainage, the whole sewerage of about 4,000,000 of inhabitants of the metropolis is averaged; that is, separately, north and south, one great system of submarine canals receives all the sewerage, and carries it, mixed, to two terminals, one for the north and the other for the south, at a considerable distance down the Thames from London. Hence the *individuality*, if we may so call it, of independent sewerages have been lost; and all of it, north and south, becomes, in one sense, homogeneous in each of these two systems.

But, despite the homogeneous character of the sewage, many difficulties arise in estimating its value, chemically. For example, up to within four days of these lines being penned, no rain of any consequence had fallen for weeks; but within the four days about an inch of rain has fallen. Consequently, an analysis taken at the two different periods, would lead to a most fallacious estimate of the sewage value. But many other circumstances occur to vitiate any special analysis. For example, the habits of 4,000,000 people vary with the temperature. In summer a much less amount of animal food is eaten; and, consequently, being replaced by vegetables and fruit, all but barren, comparatively speaking, of nitrogenous substances, phosphates, &c., the *normal* value of the sewage would be deteriorated.

But we use the word *normal* advisedly; for whilst the average value of the sewage at such a time of the year, taking its bulk, may actually be much greater than it would be at another period—although less nitrogenous and phosphatic substances would be sent into the sewer, owing to the less amount of water there, due to want of rain, and vapour evaporation—such substances *might actually appear in excess*, because the bulk of the sewage being less, the same amount of nitrogen and phosphoric salts would be dissolved or suspended in a smaller amount of water than in November, or the winter months.

Numerous other sources of error might be adduced; but we shall refrain from so doing, simply because we require our space for more important details.

The value of the Rugby sewage has already been estimated at p. 400, *ante*. The town is but small, and, altogether, has no great amount of disturbing elements. London, on the contrary, as we have just seen, is replete with such elements, and, consequently, the most extraordinary results have been arrived at. For example, a few years ago, Liebig, adopting a special analysis of the sewage of Dorset Square, which showed eighteen grains of ammonia per gallon, estimated the nominal value of London sewage at 1½*d.* per ton; but, with the addition of superphosphate of lime, he thought that a value of 4*d.* per ton might be arrived at. But subsequently Liebig dropped his estimate of the ammonia from 18 to 7·2 grains; and even that is considered, practically, as far too high to be taken as a basis for estimating the annual value of the London sewage.

Messrs. Hofmann and Witt, in a report to the main drainage committee, considered that 8·21 grains of ammonia would represent the value of a gallon of sewage; but this was subsequently reduced, by considerations of rain-fall, &c., to 4·93 grains per gallon, which would bring the value of London sewage, by itself, down to about 1¼*d.* per ton.

One method of arriving at the value, is to reckon the amount of ammonia and other valuable products evacuated by an average of both sexes and all ages of the population, and an approximation to the worth is contained in the following table. It gives the amount of ammonia voided both in the fæces and urine; the proportion of which, in adult males, is about 15·9 pounds per annum for urine, and 2·3 pounds for fæces:—

Average of both Sexes and all Ages per head per annum.

	lbs.
Urine	11·32
Fæces	1·64
Total	12·96

Thus thirteen pounds, nearly, of ammonia would have a value of about 8*s.* 4*d.* for each individual, of all ages and sexes, per annum.

But even this amount is considered too high; and, as we have previously shown, from varia-

tion in diet, it may become less in one time of the year, and greater in another. Again, there is much difference in the chemical constituents of the voidance of the two sexes. Perhaps a safe side to err upon, and one convenient for calculation, would be to place the amount of ammonia produced by urine and fæces at ten pounds per head per annum of the population. It must be remembered—and this seems to have been neglected by all authorities—that a large amount of ammonia is lost by passage into the air, arising, especially in summer-time, from the decomposition of the urea.

According to Messrs. Lawes and Gilbert, the amount of nitrogen in the food of an average individual, calculated on 86 different dietaries, arranged in 15 classes, showed a quantity equivalent to rather less than 12·2 pounds of ammonia, from which deduction has to be made of nitrogen retained in the body, and, therefore, not voided by the fæces and urine.

Admitting, however, the estimate of $12\frac{1}{2}$ lbs. per head, and including the wash of slaughter-houses, bone-boilers, manufactories of all kinds, &c., the next point to determine is, how far this ammonia and other valuable products are diminished in value, or diluted by the addition of water from rain-fall, the water-supply, and other causes.

In the absence of any reliable estimate from the reports of the north main drainage, now in active operation, and which reports could only become of value by an average of years, we fall back to the remarks of the report of the commissioners under our consideration.

"The dry-weather sewage, or sewage without rain-fall, of the metropolis, is variously estimated at from 5 to 6 cubic feet per head per day; equal, respectively, to $31\frac{1}{6}$ and $43\frac{1}{2}$ gallons per head per day, $50\frac{3}{4}$ and 71 tons per annum. According to information furnished to Messrs. Hofmann and Witt, it averaged about half-way between these two extremes—namely, about $36\frac{1}{2}$ gallons per head per day, equal to about 59 tons per head per annum. We shall, therefore, probably be not far wrong if we take 60 tons per head per annum as the average amount of the normal or dry-weather sewage. It is further variously estimated, that, by subsoil and rain-fall, the bulk of the fluid is increased by from two-thirds to an equal volume. Adopting the lower of these suppositions, which, if too low, will allow for the occasional escape of storm-water, we have the 100 pence worth of constituents distributed through 100 tons of fluid, giving to it a value of one penny per ton according to the estimated market value of its manurial constituents."

Referring to a hope that the main drainage system of the metropolis may eventually afford exact data on which the value of the sewage may be more correctly estimated, the following table is given as an approximate guide to what we may, at present, consider that value; and founded simply on the quantity of ammonia present, phosphoric acid, phosphates, common salt, and other of the numerous ingredients of sewage.

Grains of Ammonia per Gallon, and estimated Value of the Constituents in one Ton of Sewage at different Dilutions, supposing $12\frac{1}{2}$ pounds of Ammonia to represent the Chemical Value of each head of Population per annum, and from all sources.

	Ammonia per Gallon. Grains.	Estimated value per Ton. *d.*
If 60 tons per head . . .	6·51	1·67
If 70 ,, ,, . . .	5·58	1·43
If 80 ,, ,, . . .	4·88	1·25
If 90 ,, ,, . . .	4.34	1·11
If 100 ,, ,, . . .	3·91	1·00
Hofmann and Witt, from the Savoy sewer . . .	8·21	2·11
Same, diluted with two-thirds of its volume of water	4·93	1·27

It will be thus perceived that the whole question of the value of the metropolitan sewage is one that not only is replete with difficulty, but that can only be decided by practical application on a large scale. And certainly for this there is abundance of room between London and the sea, without trenching on the domain of the sea, as is proposed to be done by attempting to enclose and fertilise the Maplin Sands, off the east coast of Essex. From East Woolwich to the Nore, at least fifty miles of land exists, chiefly of a marshy character, level, and extending from a short distance to two or three miles inland. Here is a grand opening for the most extensive trial of the value of sewage, which, in the absence of any known measurement, but with intimate personal knowledge of the district, we should consider estimated exceedingly low at fifty square miles. For a great portion of the distance the land is a dead level, superficially, and, of course, apart from the natural curve of the earth. A large proportion is chiefly loose sand, that extends again northerly from Barking inland to the Wash, at Boston, in Lincolnshire. No place in the world is *so well* adapted for sewage trials; for none other has 4,000,000 inhabitants cooped up in a few square miles; and, at the same time, hundreds of square miles of comparatively level country to throw the sewage on by gravitation, or, comparatively speaking, trifling engineering expense.

So far we have endeavoured to lay the question of metropolitan and other sewage utilisation impartially before our readers. Our opinion is, that the great dilution of London sewage, *as now collected, or about to be, at the terminals of the main drainage system,* will be a bar to its profitable employment, except, possibly, in patches near the places just referred to. We believe the cost of transit, by *any* means, to a greater distance than a few miles from the metropolis, will be so great as to make it far too costly; and that any attempt to effect that transit by means of engineering arrangements, to the distance—upwards of fifty miles—that has been proposed, will prove a singular and disastrous *pecuniary* failure, however fertile the sands may become

when they have the good fortune to taste the excreta of the metropolitan population.

Having disposed of the chief points of practical interest in connection with the experiments at Rugby, and the question of the utilisation of the metropolitan sewage, a few words may be added, descriptive of what has been done at Croydon and Edinburgh: the system adopted at the latter city has been already frequently alluded to.

"The population of Croydon contributing (1865-'6) to the sewage-tanks, is about 16,000; and the water contributed to them is estimated at about 40 gallons per head per day, without rain-fall; and to average, the year round, perhaps 60 gallons per head per day with rain-fall. These amounts are equal to about 65 tons per head per annum without, and 98 tons with, rain-fall. About 300 acres are rented, by the local Board of Health, at £4 per acre without sewage, and sub-let, to Mr. Marriage, at £5 per acre with sewage. Up to Midsummer, 1864, 260 acres had been prepared for irrigation; of which about 250 might be considered as actually under irrigation during the year. It was intended to have 90 to 100 acres constantly under Italian rye-grass; but, as yet, not so large an area was under the crop.

"The plan of irrigation is to let the sewage flow over from twenty to thirty acres for about four days and nights, and to give three such dressings between each cutting. As much of the water as can be recovered for the purpose is re-distributed, and in this way a large proportion is always used at least twice—sometimes three and even four times over—and, on an average, about 2½ times, by which its utilisation and purification are rendered much more complete than otherwise would be the case. According to the figures given above, there are about 6,250 tons of the dilute sewage with rain-fall, annually available for each 250 acres; but, as so much water is re-used, the average amount passing over each acre is very much more. There are also annually available for each acre the excretal matters of about sixty-four individuals, of the mixed population of both sexes and all ages.

"The land under sewaged Italian rye-grass is estimated to yield at least four cuttings, and from thirty to thirty-five tons of green produce per acre per annum. The cuttings commence in April, and last to the end of October, and even into November. The grass sells for about 25*s.* per ton in London, and is estimated to realise from 16*s.* to 17*s.* per ton on the land. The sewaged meadow grass also yields at least four cuttings annually; but it is much less liked than the Italian rye-grass by the London feeders, and is generally sold on the land by the rod, or grazed, and is estimated to yield several pounds less gross money return per acre per annum than the rye-grass.

"About 180 tons of moist solid matter are annually deposited or intercepted by strainers at the tanks, and are sold by the Board at a very low price per ton."

An analysis, which, however, must not be absolutely depended on, showed the constitution of the sewage, before irrigation, to be as follows, in grains per gallon:—

Inorganic matter	48·30
Organic do.	52·20
Total	100·50
Ammonia	6·70

But the constituents vary considerably in proportion.

After drainage from the sewage matter analysed as above, and percolating the land, the analysis gave:—

Inorganic matter	23·40
Organic do.	2·40
Total	25·80
Ammonia	0·21

Showing, as was evidenced, in respect to the Rugby sewage and drainage, how much of the valuable constituents of the fluid were absorbed and retained by the soil.

The sewage meadows near Edinburgh have long been noted for the successful application of the sewage of towns, and present a remarkable instance of what may thus be effected; and from lengthened personal acquaintance with them, we do not hesitate to affirm that they will well repay the visit of the intelligent agriculturist.

The most important division is the Craigentinny, where about 200 acres of meadow are irrigated by gravitation. A great proportion was only barren land abutting on the sea; indeed, the banks are washed by the Forth at high water. Another portion consists of good loamy soil. During the summer, the sewage is constantly applied day and night; but in the winter, only during the day. "The general plan, in the summer, is to let the whole of the sewage water go over from 2 to 2½ acres at a time, changing every three or four hours during the day; but less frequently during the night: and the application is so timed as to get over, on the average, about sixty acres per week, and to give each acre such a dressing about once in the winter. The distribution over about one hundred acres can be attended to by one man; but the cleaning of the runs, keeping the roads, &c., require additional labour. Four to five crops are obtained annually; though four, cut at proper times, generally yield more, and leave the herbage in better condition, than when five are taken. From good, well-managed meadows, with sewage as liberally applied as on the gravitation meadows at Craigentinny, Mr. Bryce, the manager, thinks about sixty tons of green grass should be obtained per imperial acre annually. The price varies, according to the season and other circumstances, from 6*d.* to 1*s.* 2*d.* per cwt. on the ground standing. The produce consists almost entirely of rough meadow grass, which is considered the most valuable; couch, which is looked upon as a very good grass, and of a

very rapid growth; and common rye-grass, which is also considered a good grass, but not to give so close a bottom as the others.

"Arrangements are also made for irrigating some higher land, by raising the sewage about twenty feet, it being first brought into a large tank by means of a deep under-ground drain from the highest level of the natural flow, and thence pumped into open channels for surface distribution. Only about sixty imperial acres are now so irrigated; but, formerly, a larger area was under treatment. The application is continued from April to October, inclusive, and each plot gets six dressings, and yields three cuttings annually. If it was not for the cost of lifting, more of this land would be laid down as permanent meadow, and much more sewage would be put upon it; but the supply being so limited by the cost of application, Mr. Bryce thinks it better to sow Italian rye-grass; break up every two years, and grow potatoes; re-sow rye-grass; and so on."

Although the Craigentinny meadows are chief in importance in respect to the utilisation of the Edinburgh sewage, still they form but a portion of those that are thus irrigated. The following table will show how far land, available near Edinburgh, has been submitted to the action of sewage irrigation.

	Acres.	Approximate Population contributing per Acre.	Sewage provided each Acre.
			Tons.
Lochend Spring Gardens and Craigentinny	285	337	20,500
Roseburn and West Dalry	80	112	17,000
Quarry Holes . . .	8	562	65,000
Broughton Burn . .	6	1,666	102,000
The Grange	16½	302	97,000

The Lochend and Spring Gardens occupy about thirty-five acres, and are irrigated by the Edinburgh sewage before it reaches Craigentinny. Each acre gets a flow of a stream of sewage 12 inches wide by 8 deep, falling at a rate of 2 miles per hour, for 10 days of 16 hours annually, and equal to about 31,000 tons per acre per annum. The herbage consists of meadow-grass, the *Poa trivialis*, and couch, *Triticum repens*, besides crow-foot and other grass.

On a portion of higher-lying land, which is irrigated by the aid of a water-wheel, worked by the sewage stream itself, and where the supply is necessarily more limited, Italian rye-grass is grown, which involves the periodical breaking up of the land.

After two years under the rye-grass, a crop of potatoes is taken; then Italian rye-grass is sown again, and so on.

The Roseburn and Western Dalry meadows, on the west of Edinburgh, are next in importance to those of Craigentinny, and comprised formerly 800 acres, but now limited to about eighty, having been curtailed by railway and other requirements. The soil is partly gravel and loam, with a subsoil of clay. The sewage coming to these meadows includes the refuse from extensive slaughter-houses, and also that from a very large distillery. It is used all the year round, both day and night; and on Sundays, when it can be conveniently left to flow from Saturday night to Monday morning. In summer, the water seldom goes over the same piece of land more than a few hours together, as long as may be necessary, thoroughly to soak it. The land is generally watered only twice, but occasionally three times between the cuttings. In winter, the water is allowed to flow for a longer period, over a given area, in order to "feed" the land as much as possible. In laying down permanent meadows for irrigation, a great variety of grasses has been sown; but the soil has made its own selection, and those unsuitable to it have died out.

The Grange meadows are situated to the south of Edinburgh, occupying an area of about 16½ acres. Owing to bad house drainage, the amount of sewage produced is but small. The grass largely consists of couch and crow-foot. The annual sales of grass bring in from £13 to £38; the difference of price depending on a deficiency of sewage.

The Rose Bank meadows, or Broughton Burn, have only an extent of six acres, but have an available sewage of above 100,000 tons annually. The irrigation is constantly kept up. Four or five cuttings are made annually, and the return per acre annually runs from £25 to £30. An adjacent garden-ground is also supplied with sewage, which has been found beneficial to turnips, cabbages, and onions.

The Quarry Holes meadows have an area of about eight acres, and a total sewage-supply of 65,000 tons annually, which is constantly supplied, except when frost occurs. "There is no doubt that there is extravagant expenditure of manurial constituents here, as there is, indeed, in all the other cases; but it must, at the same time, be admitted, that it is under these conditions that a greater amount of produce is obtained per acre, under the influence of sewage, than anywhere else; and, perhaps, among all the Edinburgh sewage meadows, those of the Quarry Holes stand second to none in point of evenness of herbage, and amount or value of produce per acre. The grasses are rough meadow and common couch."

The preceding is a brief account of the leading area of meadows under sewage treatment at or in the neighbourhood of Edinburgh. The remarks are mostly extracted from the report of the commissioners, because it was thought that their authority would be most conclusive. But, from personal experience, we can bear the fullest testimony as to the valuable effects the sewage exerts. The Craigentinny meadows, and those adjacent, we have watched all but daily; for several years, 1856—'60, attended the "roup," or auction sale of grass; and otherwise had opportunities of judging of both the real and estimated value of the produce. Having pre-

viously intimated an acquaintance with most of the farm lands, pasturage or arable, of the greater portion of England and Scotland, we can only express the great surprise that must be felt at the extraordinary fertility of the meadows now under detail. Exposed, for a large portion of the year, to a strong and, cold north-east wind; on the very shores, and, indeed, forming those of the sea (the mouth of the Forth); for the greater part formed of sand, and otherwise, in the absence of the sewage, unfertile—these meadows present an astonishing instance of the value of sewage judiciously applied by gravitation, and apart from all engineering arrangements. We have no hesitation in saying, that if the neighbourhood of London presented similar facilities of level, &c., the use of the metropolitan sewage would, in its results, present a far greater pecuniary recompense for the adoption of such a system of irrigation, especially as many of the obstacles of temperature, climate, &c., would be absent as compared with such existing near Edinburgh. For about two centuries, this method of utilising the sewage has been in operation near that city; and the results we have related have a parallel only in the fertile plains of the deltas of rivers, or similarly placed localities, referred more particularly to at p. 352, *ante*.

8. *Chemical Composition of Unsewaged and Sewaged Grass.*—In respect to this very important point, the commissioners observe—"It has been seen, that, reckoned in the fresh or green state, a greater weight of sewaged than unsewaged grass is required to yield a given amount of milk or increase in live-weight; but that less of the dry or solid substance of the sewaged grass is required to produce a given amount of milk or increase. It was further found that, especially in the case of the sewaged grass, it required less, both of green grass and of dry substance of grass, to yield a given return of milk during the earlier than the later portions of the season, and also less in one season than in another. It is obviously important, therefore, to ascertain the difference in the proportion of dry and solid substance, and the difference in the composition of the solid substance itself, of the grass grown with and without sewage, with smaller and larger quantities of sewage, at different periods of the season, and in different seasons. * * * *

"Comparing, first, the composition of the grass produced under different conditions, in one and the same season, it is seen that in each season there is a very great difference, both in the proportion of the dry substance, and in the composition of that dry substance, according to the varying circumstances of growth. With scarcely an exception in either season, the proportion of dry or solid substance in the grass, as cut, weighed, and given to animals, was considerably lower in the sewaged than in the unsewaged grass; and, generally, the lower was the quality in relation to the largest use of sewage. There was, also, very uniformly, a diminished proportion of dry substances in each successive cutting as the season advanced.

"It will be readily understood that the proportion of dry or solid substance in the grass depends upon the stage of growth, the proportion of leaf or stem, and the condition of the weather at the time of cutting. The grass grown without sewage was, for the most part, cut at a later stage of growth, and showed more tendency to form stem and seed than that grown with it. The greater the quantity of sewage used, the greater was the production of succulent leaf; though, even with sewage, the tendency to run to seed is much greater in hot and dry than in cold and wet seasons. Then, again, the earlier crops of the season are not only grown under much more favourable maturing conditions, but, from their much greater abundance, they are generally cleared more slowly, and are therefore liable to be in a more advanced stage when cut; whilst the later crops are not only produced under less favourable maturing circumstances, but are frequently much more affected in their condition by unfavourable weather."

Our readers have already seen that the experiments were tried in two fields. That of five acres' extent was level; whilst the ten-acre field was full of inclines, and sloping. The following table indicates the results of analyses conducted on the products of each for three successive years—1861, 1862, and 1863. We have only given the mean results, stating, at the same time, that the earliest crop was the most productive.

Per-centage of Dry Substance in the Unsewaged and Sewaged Grasses.

		Unsewaged.	Sewaged.
Meadow grass,	1861	26·2	17·5
" "	1862	24·8	16·3
" "	1863	35·3	16·0
Italian rye-grass,	1863	28·3	19·0

The preceding table simply gives the total of dry substance per cent. of the grass in either case; but more exact analyses were effected, showing the actual chemical composition of that dry substance, produced with and without sewage, in each successive crop of the years 1861, 1862, and 1863. The following table indicates a mean result of such analyses:—

Mean Composition, per cent., of the Dry Substance of the Grass, with and without Sewage (Meadow Grass).

	Unsewaged.	Sewaged.
Nitrogenous substance ($N \times 6{\cdot}3$)	13·08	18·92
Fatty matter (extracted by ether)	3·21	3·53
Woody fibre	28·80	30·15
Other nitrogenous substances	45·66	35·94
Ash	9·25	11·46
	100·00	100·00

The preceding analysis is for 1861; but it varies so much from the results obtained in

1862-'63, and for each successive crop in either year, that we should advise our readers to place but little confidence in the result, and to draw the conclusion that the physical conditions, already referred to at p. 365, and subsequent pages, *ante*, are of equal importance with any chemical result that an analysis can afford.

It is stated that, with Italian rye-grass, as well as with meadow grass, the herbage, in the condition in which it was cut, was found to be more succulent when grown with sewage than without it. In the case of rye-grass, however (though, it is true, only small quantities of sewage were applied, and the results relate to only one season), the diminution in the proportion of dry substance, as the season advanced, was somewhat less marked.

The general result is, that there was a less proportion of dry or solid substance in the sewaged grass as cut, than in the unsewaged; but that a given amount of dry substance in the sewaged, was more productive of milk and increase than an equal amount of it in the unsewaged grass.

The question arises—was there any difference in the composition of the dry or solid substance of the unsewaged and the sewaged grass, which might account for the higher food qualities of the sewaged ?

The summary table of the commissioners, of which we have given a brief abstract (headed *Mean Composition, per cent., of the Dry Substance, &c.*), shows to us the fact, that the most remarkable difference was in the proportion of the nitrogenous constituents, the per-centage of which was, in each season, much higher in the solid matter of the sewaged than in that of the unsewaged grass, and also it was higher in proportion with the greater amount of sewage applied. The proportion of the green and impure fatty or waxy matter was also different, but in a less degree than the nitrogenous substance; it was greater in the sewaged grass. The comparatively indigestible matter, or woody fibre, judging from the results of 1862 and 1863, when the sewage crops were cut in a younger and more favourable condition than in 1861, probably average less in sewaged than in unsewaged grass. But the mineral matter, like the nitrogenous and green fatty or waxy matter, is of larger amount in the sewaged grass; and like them, also, a relatively large amount of it is generally indicative of a more ripe and succulent condition.

That the higher milk-yielding qualities of the solid matter of the sewaged grass do not depend simply on its higher per-centage of nitrogenous constituents, is evident from the fact that the solid matter of the later crops of the season—which, weight for weight, had much less value as food than that of the earlier—contained a very much larger proportion of nitrogenous substance. Indeed, there was generally more than twice as much nitrogenous substance, in a given amount, in the solid matter of the last than of the first crop of the season.

It would appear that the higher qualities of the solid matter of the sewaged grass, and of the grass grown in the earlier and more genial periods of the season, were due rather to a favourable condition of maturation, and, therefore, of digestibility and assimilatility of the constituents. That the condition of maturation or elaboration of the constituents had much to do with the quality of the grass is evident, from the fact that the produce of the warmer seasons of 1861 and 1863, was much more abundant than that of the cold wet season of 1862: and that a comparatively higher per-centage of nitrogenous substance is only advantageous when accompanied with a favourable condition of maturation, may be gathered from the fact, that with the higher per-centage of nitrogen in the produce grown in the more favourable seasons of 1861 and 1863, there was higher feeding quality, whilst with the higher per-centage of nitrogen, in the produce grown in the later and colder periods of the season, there was lower feeding quality.

Italian rye-grass seems to be subject to very similar variations in composition by the application of sewage, and at different periods of the year, as meadow grass; but as the amounts of sewage applied to it were comparatively small, and the results relate to one season only (see *ante*, p. 398), it can scarcely be judged with certainty whether or not the changes in composition would, under comparable circumstances, be much the same in degree as well as kind with the two descriptions of herbage. The feeding results seem to indicate that the Italian rye-grass deteriorated somewhat less than the meadow grass as the season advanced; but the difference in chemical composition offers no very obvious explanation of the fact.

9. *The Effects of Sewage on the Mixed Herbage of Grass Land in developing the more freely growing, at the expense of less freely growing, Plants.*—As this is one of the essential points of importance to the farmer, directing him to the choice of such grasses as are most suitable for growth on land supplied with sewage, we shall give the greater portion of the report of the experiments as furnished by the commission.

It is well known that active manures of any kind, when applied to the mixed herbage of grass land, develop certain more freely growing plants, to the partial, or, in some cases, entire exclusion of others. Irrigation, whether by sewage or otherwise, produces very similar effects.

On careful inquiry, and by the aid of samples obtained from some of the most important sewage meadows in the neighbourhood of Edinburgh, it was found that, wherever the application has been continued for a considerable number of years, the produce consists almost exclusively of rough meadow grass (the *Poa trivialis*), common couch grass (*Triticum repens*), and, in a smaller proportion, of rye-grass (*Lolium perenne*), or rough cock's-foot (*Dactylis glomerata*), or both; the chief weed being crowfoot (*Ranunculus*), of various species [that is, the ordinary buttercup]. In four out of five reports from as many different sewage farmers, *Poa* is said to stand first, and the couch grass second,

in degree of prominence. The *Poa* also seems to stand first in estimation as sewage grass; whilst the common couch is also much valued. Indeed, Mr. Thomson, of Roseburn, informs us that he has actually transplanted this weed of our corn-fields from his arable land, to lay down for sewage meadow, and that the result has been quite satisfactory: he also informs us, that, when he has sown as many as fifteen or twenty different kinds, most of them have gradually died out; and, after some years, only a few suitable to the land and the treatment remained.

"At Rugby, similar effects, but, at present, in a less degree, have been produced. The following observations on the character of the herbage in the two fields, are founded upon the records of a careful examination made in August, 1862; since which time, however, further change has, doubtless, taken place on the sewaged plots."

The portion of the land left unsewaged by the commissioners in the five-acre field, had received less sewage previously than that in the ten-acre field, and showed somewhat greater complexity in herbage.

In the five-acre field, the most prominent grasses on the sewaged portion were woolly soft grass, or *Holcus lanatus;* common bent-grass, or *Agrostis vulgaris;* rough meadow grass, or *Poa trivialis;* hard fescue, or *Festuca duriuscula;* rough cock's-foot, or *Dactylis glomerata;* and rye-grass, or *Lolium perenne;* with a number of others in smaller proportion. The herbage also comprised several species of the Leguminous family, besides a number of weeds; of which the most prominent were—ribwort, or *Plantago lanceolata;* milfoil, or *Achillœa millefolium;* sorrel-dock, or *Rumex acetosa;* and dandelion, or *Taraxacum dens-leonis.* In the ten-acre, as in the five-acre field, the cock's-foot, woolly grass, rye-grass, and hard fescue, were among the most prominent of the grasses without sewage; whilst the rough meadow grass, and others, were less prominent than in the five-acre field. The amount of leguminous herbage was also less than in the five-acre field; whilst crow-foot was extremely abundant.

In the sewaged herbage of both fields, the cock's-foot and woolly soft grass were by far the most abundant; the rye-grass coming next; and, perhaps, the rough meadow grass, or the hard fescue, next; others being more reduced. In both fields the leguminous herbage was much reduced, in proportion, under the influence of sewage; whilst in the five-acre field, the sorrel-dock, and in the ten-acre field, the crow-foot, were the most prominent weeds.

In sewage meadows near Croydon, the cock's-foot and rye-grass appear to be the predominating grasses.

The general effect of sewage irrigation on the mixed herbage of meadow land, may be stated to be—to develop the graminaceous herbage chiefly; to nearly exclude the leguminous; and to reduce the prevalence of miscellaneous or weedy plants, but much to encourage individual species. It also, at the expense of the rest, encourages a few free-growing grasses, among which, according to locality and other circumstances, the rough meadow grass, couch grass, rough cock's-foot, woolly soft grass, and rye-grass, have been observed to be very prominent. The result is, an almost exclusive graminaceous and very simple herbage. But, as the produce of sewage irrigated meadows is generally either cut or grazed in a very young and succulent condition, the tendency which the great luxuriance of a few very free-growing grasses has to give a coarse and stemmy later growth, is not an objection, as it is in the case of meadows left for hay. Indeed, as has been already shown, when the produce is given to animals in a green and succulent state, a certain weight of the dry or solid substance of the simple sewaged grass, is more productive than an equal weight of the complex unsewaged produce.

11. *Experiments on the Application of Sewage to Oats.*—These experiments were carried on in the year 1863, on four plots, of about an acre each, which were set apart, and treated as follows:—

Plot 1 was left unmanured.

Plot 2 was sewaged at the rate of 135½ tons per acre.

Plot 3 was sewaged at the rate of 510 tons per acre; and

Plot 4 was top-dressed with 1½ cwt. of nitrate of soda.

"The applications of the sewage and of the nitrate were made much later in the season than was desirable. The sewage was applied from April 28th to May 16th, inclusive; the two acres requiring, with the hindrance of gauging by means of a barrel, sixteen days for the application, by hose and jet, of the small quantities stated. The nitrate of soda was sown broadcast partly on April 24th, and partly on May 4th.

"For several weeks from the time of sowing there was very little rain, so that the plant top-dressed with nitrate of soda was obviously injured by the application for some time; the foliage being much 'burnt.' The sewage, on the other hand, being applied during dry weather, and the application followed by a very unusually dry period, during which, spring corn, and even wheat crops were reputed, over a considerable range of country, to be suffering from want of rain, produced, as might be expected, very marked effects. Owing, too, to the small amount of rain, the sewage was of more than the average concentration of that of Rugby, and, probably, about double the average strength of the metropolitan sewage, including rain, &c."

The results were, that under the conditions of the season described, there was, with the nitrate of soda, even rather less corn, and only about 3 cwt. more straw than without manure; and the smaller quantity of sewage gave more increase of corn than the larger, though the latter gave considerably the most straw. Both the sewaged crops were, indeed, too luxuriant to bear up against the heavy rains of June; and the one with the largest amount of sewage was

very much laid; and hence the deficient yield of corn in proportion to straw. * * * * The defective result as to corn, in this case, was due to over rather than to under luxuriance. In fact, the usual complaint, when sewage has been applied to growing corn crops, has been of over-production of straw, and deficient production of corn—that is to say, of a tendency of growth, which is as unfavourable in the case of corn, as it is favourable in that of grass.

"There was, however, a very high gross money return per ton. of sewage applied, at any rate, where the smaller quantity only was employed. Thus, reckoning oats at 3*s.* per bushel, and oat straw at 20*s.* per load, the gross value of the increased produce from one ton of sewage, was—

With $135\frac{1}{2}$ tons of sewage per acre	$5\frac{1}{4}$ per ton.
With 510 tons of sewage per acre	$1\frac{1}{2}$ per ton.

"Here, then, with a small quantity of sewage of nearly double the average strength of that of the metropolis, applied during a period of very dry weather, which was followed by a season of unusual productiveness—the harvest of 1863 being the best for many years past—the gross value of the increased produce amounted to more than 5*s.* per ton. of sewage employed, or to nearly three times the market value of the constituents of the sewage, supposing them to have been extracted and dried.

"The smaller amount of sewage applied was equivalent, in water, to something under an additional $1\frac{1}{2}$ inch of rain-fall at the critical period of growth; and the larger amount was equal to about 5 inches, which, at that period, would have been a very great excess, and of itself caused rank and over-luxuriant growth on any soil in such condition as the unmanured produce showed the one in question to have been. It is, indeed, difficult to say how much of the actual result was due to the manurial constituents, and how much to the water of the sewage. At any rate, whether considered with regard to the amount of manurial constituents supplied, or that of the water, an average of 500 tons of sewage per acre to arable land otherwise treated in the ordinary way, would most probably be found more than appropriate to the average of soils and seasons; and would most certainly be more than appropriate for heavy lands, and for wet seasons. Nor even in dry seasons, when sewage would be worth a maximum value for some crops by virtue of its water, if applied at the proper time, would more than this amount be required the year round; though it is possible that the demand might be as much beyond the supply for a short period, as the supply would undoubtedly be beyond the demand for very much the greater part of the year, so far as arable land is concerned."

We have thus brought before our readers all the most important parts of the report of the commissioners, in respect to the economic application of sewage to the purposes of the farmer, dealing with each of the headings of the report chiefly in its own words, and therefore putting the question in an impartial manner, in all possible respects, for the judgment of the farmer on the facts adduced. The conclusion, whilst partially favourable, is, on the whole, by no means encouraging; for it is evident, that unless the farmer gets the sewage for nearly nothing as regards first cost, it is of no value to him. Indeed, the commissioners state, that "at Rugby, where, for eleven years, arrangements have been made for the distribution of small quantities of sewage over a large area, and to all crops, and where the sewage is much stronger than that of the metropolis, the cost to the tenants averages about three-farthings per ton at the hydrants in the fields. Yet both the present tenants have been glad, rather than incur the loss of using sewage themselves at that cost, to get rid of it, for the purpose of these experiments, at sums which, though three times as high during the six summer as during the winter months, have averaged, the year round, scarcely, but very nearly, 1*d.* per ton at the hydrants."

The *general conclusions* at which the report arrives are as follows:—

To obtain a maximum amount and gross value of produce from a given amount of sewage, it should be applied in small quantities per acre, and in dry weather; but the great dilution of town sewage, its large daily supply at all seasons, and its greater amount in wet weather, when the land can least bear, or at least requires more water, render it quite inappropriate for application, on a comprehensive scale, to arable land for corn and other ordinary rotation crops.

Supposing arrangements were made for distributing sewage over a sufficiently large area to command a full value, both as manure and as water, at the most favourable periods of the year, the cost of main distribution would be very great. The application to the arable land would require to be chiefly by the expensive means of piping, and hose and jet, instead of open runs; and but a small proportion of the total sewage could be so used, leaving the remainder to be applied, in large quantities, to grass land at the less favourable periods of the year, and, of course, to realise a lower value.

Having regard to the cost of distribution, it is probable that the most profitable mode of utilisation would be to limit the area, by specially adapting the arrangement for the application of the greater part, if not the whole, to permanent or other grasses, laid down to take it the year round, trusting to the occasional use to other crops within easy reach of the line or area so commanded, but relying mainly on the periodically broken-up rye-grass land, and on the application to arable land of the solid manure resulting from the consumption of the sewaged grass, for obtaining other produce than milk and meat by means of sewage.

It is probable that about 5,000 tons of sewage per acre, judiciously applied to grass land properly laid down to receive it, would, in a great majority of cases, seem the most profitable utilisation.

Supposing an application of 5,000 tons of sewage per acre per annum to grass land, the purification of the water would, doubtless, be sufficient to admit of the drainage being turned into rivers without fear of detriment to fish, whilst any stream receiving such drainage instead of that [the sewage] direct from towns, would, at any rate, be vastly improved from the previous condition as a water-supply; but whether the purification would be sufficient with such an application, is a question which requires further experience and investigation to answer satisfactorily, and which will, probably, receive a different answer in varying cases.

Assuming that the average dilution of the metropolitan sewage, including rain-fall and subsoil water, will amount to 100 tons per head per annum, 5,000 tons would represent the excretal and other matters of fifty average individuals; and a population of 3,000,000 would require about 60,000 acres constantly under irrigation.

The only records of exact quantitive results obtained on the application of town sewage to corn crops, are those of the experiments of the Earl of Essex on wheat, and those of the experiments with oats at Rugby (see *ante*, p. 410); and in both cases the increase of produce represented a very high gross money return per ton of sewage employed. The circumstances of the experiments at Rugby were, however, quite exceptional; and where the most extensive trials of the application of sewage to corn crops have been made, with a view to profit—namely, at Watford, Rugby, and Alnwick—the practice has been abandoned; whilst neither at Edinburgh nor Croydon, where the best results have been obtained with grass, does the application to corn, and other rotation crops, constitute a part of the general system adopted.

Judging both from the results of the experiments, and from the experience of common practice, it is considered that the most profitable utilisation of town sewage will, in most cases, be attained by the application of about 5,000 tons per acre per annum to meadow or Italian rye-grass; but that the farmer would not pay $\frac{3}{4}$*d.*, and, probably, not $\frac{1}{2}$*d.* per ton, the year round, for sewage of the average strength of that of the metropolis (excluding storm-water), delivered on his land.

The preceding are the *general conclusions* at which the commissioners arrived, and which should form the guide for a farmer, or town council, in determining how far the utilisation of sewage may be effected economically and profitably. The bases of such conclusions consisted in the facts that have already been brought forward (or, rather, summarised from the report); but a few brief extracts from the general summary of such facts as given officially, may not only refresh the memory of our readers, but also place the facts in a more concise and intelligible point of view.

Using the words of the report, the results of the whole inquiry may be briefly enumerated as follows:—

1. As there is a daily supply of sewage all the year round, which, on sanitary and engineering grounds, it is essential to dispose of as soon as produced; and as passing it over land is the best mode of purifying and utilising it, the sewage should be employed for purposes of irrigation; and be applied in winter, when of little comparative value, as well as in summer, when of greater value.

2. As regards the application of sewage to meadow and Italian rye-grass, by so doing during the winter months, a very early cut or bite of green food may be obtained; but the amount of increased produce due to winter application, is comparatively small for the amount of sewage employed.

3. By means of sewage irrigation, the period during which an abundance of green food was available, was extended considerably at the end as well as at the beginning of the season; and the more so the larger the quantity of sewage employed—namely, 9,000 tons per acre.

4. One of the experimental fields gave much less produce per acre without sewage than the other, and analysis showed its soil to be much less fertile; but it gave fully as much produce per acre, under the influence of liberal dressings of sewage, as the naturally much more fertile soil.

5. Taking the average of over three years, and in the two fields, the amount of produce obtained, *without* sewage, was about $9\frac{1}{4}$ tons of green grass per acre per annum, which is equal to about 3 tons of hay; and, with 3,000, 6,000, and 9,000 tons of sewage per acre per annum, the amounts were, respectively, $22\frac{1}{4}$, $30\frac{1}{4}$, and $32\frac{1}{4}$ tons of green grass—equal, respectively (reckoned according to the per-centage of dry substance in each), to about 5, $5\frac{3}{4}$, and $6\frac{1}{2}$ tons of hay.*

6. The largest quantities of produce, per acre, were obtained in the third year of the experiments, and with 9,000 tons of sewage per acre per annum—namely, on one field, 35 tons, and, on the other, 37 tons of green grass; equivalent, respectively, to about 6 tons $12\frac{3}{4}$ cwts. of hay, and 7 tons 1 cwt. of hay.

7. The average increase obtained for each 1,000 tons of sewage was—when 3,000 tons per acre were applied, about 5 tons of green grass; when 6,000 tons were applied, 4 tons $2\frac{1}{2}$ cwts.; and when 9,000 tons were applied, 3 tons $3\frac{1}{4}$ cwts. of green grass.

8. The amount of produce per acre was the greater the larger the quantity of sewage applied up to 9,000 tons per acre; but the amount of increase of produce obtained for a given amount of sewage was the less when the greater amounts were applied.

9. Experiments with rye-grass were made in one season only; sewage was not applied until the end of April, and comparatively small quantities were put on. The results so obtained indicated much about the same increase of produce for a given amount of sewage as with meadow grass.

In respect to the results of fattening oxen—

10. When cut and given to fattening oxen,

* See note at foot of p. 396, *ante*.

tied up under cover, more sewaged than unsewaged grass, reckoned in the fresh or green state, was both consumed by a given weight of animal within a given time, and required to produce a given weight of increase ; but of real dry or solid substance, less of that of the sewaged than of the unsewaged grass was required to produce a given effect.

11. When cut grass was given alone, the result was very unsatisfactory ; but when oil-cake was given in addition, the amount of increase upon a given weight of dry substance of food consumed, was not far short of the average result obtained when oxen are fed under cover on a good mixed diet.

12. The money return, whether reckoned per acre or for a given amount of sewage, was much less with fattening oxen than with milk.

In regard to the effects of sewage on milking-cows—

13. When cows were fed on unsewaged or sewaged grass with as much as they chose to eat, a given weight of the animal was more productive, both of milk and increase, but especially of milk, on the unsewaged than on the sewaged grass.

14. From a given weight of unsewaged grass, reckoned in the fresh or green state, more milk was produced than from an equal weight of sewaged grass ; but a given weight of the dry or solid substance of sewaged grass was, on the average, more productive than an equal weight supplied in unsewaged grass.

15. The milk-producing quality of the grass was very varying in different seasons, and at different periods of the same season. It was very inferior in the wet and cold season of 1862, and towards the close of the season, as compared with the earlier period. It appears probable that Italian rye-grass deteriorates less towards the end of a season than does meadow grass. On the average, about six parts, by weight, of fresh grass yielded one part, by weight, of milk.

16. By the aid of sewage, the time that an acre would keep a cow, and the amount of milk yielded from the produce of an acre, were increased between *three* and *four*-fold.

17. So far as the results of the experiments afford the means of judging, it is estimated that, with an application of about 5,000 tons of sewage per acre per annum to meadow land, an average gross produce of not less than 1,000 gallons of milk per acre per annum may be expected.

18. In experiments conducted with Italian rye-grass (but in one season only), more milk was obtained by the use of a given amount of sewage applied to it than to meadow grass.

19. With an application of about 5,000 tons of sewage per acre per annum, an average gross return of from £30 to £35 per acre in milk, at 8*d.* per gallon, may be anticipated.

In reference to the composition of the Rugby sewage—

20. The mean of ninety-three analyses of as many samples of the Rugby sewage, collected over a period of thirty-one months, shows 6½ grains of ammonia, and 87½ grains of total solid matter per gallon ; equal to 207¾ pounds of ammonia, and 2,803 pounds of total solid matter per 1,000 tons. Or, taking the mean of the averaged composition fixed by the analyses for each of the thirty-one months, instead of the direct mean of the total ninety-three analyses, the averaged contents would be almost exactly 7 grains of ammonia, and 92½ grains of total solid matter per gallon ; equal to 224 pounds, or 2 cwts. of ammonia, and 2,960 pounds, or about 26½ cwts. of total solid matter per 1,000 tons.

21. Although each sample analysed was the result of a mixture of portions taken every two or three hours for several days together, the variation in composition, at different times, was very great ; the amount of ammonia varying, in the different mixed samples, from 2½ to about 15½ grains per gallon, or from 81½ to 500½ pounds per 1,000 tons ; whilst the total solid matter varied from about 31½ to about 270 grains per gallon, or from 1,203 to 8,637 pounds per 1,000 tons.

22. One thousand tons of the average sewage of Rugby represent the excretal and other matters of from seventeen to eighteen average individuals of a mixed population, of both sexes and all ages, for a year, and contain ammonia equal to that in from 11 to 12 cwts. of Peruvian guano ; or about 1,700 tons of such sewage would contain nitrogen, reckoned as ammonia, equal to that in one ton of Peruvian guano.

23. It is estimated that there are, at Rugby, including rain-fall, &c., on the average, from 55 to 60 tons of sewage per head of the population per annum.

24. Judging from the average composition of the Rugby sewage, and of various crops, it is concluded that potash would be more likely than phosphoric acid to become deficient where town sewage was applied constantly to grass land, whilst phosphoric acid would be more likely to become deficient than potash, if it were applied to the ordinary crops of rotation.

In regard to the estimated average composition of the metropolitan sewage—

25. There is, as yet, no record of the analysis of any samples or sample of sewage, collected under circumstances fairly to represent the average metropolitan sewage, either with or without rain-fall and subsoil water.*

26. It is estimated that the metropolitan sewage amounts, on the average, to about 60 tons without, and, probably, to about 100 tons with, rain-fall and subsoil water, per head of the population per annum.

27. It is estimated that, including human excretal and other matters, there are annually contributed to the metropolitan sewage about 12½ pounds of ammonia per head of the mixed population of both sexes and all ages.†

28. Reckoned according to the currently adopted trade prices of the several constituents, taking dry and portable manure as the standard, the total annual value of the manurial constituents contributed to the sewage, supposing

* See, generally, pp. 404 and 405. † *Ibid.*

them to be extracted and dried, would amount to 8s. 4*d.* per head of the population.

29. Accordingly, in the dry-weather sewage of the metropolis, reckoned at 60 tons per head per annum, there will be about $6\frac{1}{2}$ grains of ammonia per gallon; and the manurial constituents in 1 ton, if extracted and dried, would be worth about $1\frac{3}{8}d.$ In the average sewage, with rain-fall, &c., reckoned at 100 tons per head per annum, there will be scarcely 4 grains of ammonia per gallon; and the total manurial constituents in 1 ton will have an estimated value of 1*d.*

30. One thousand tons of the average metropolitan sewage, without rain-fall, reckoned at 60 tons per head per annum, represent the excretal and collateral manurial matters from nearly seventeen average individuals, and contain ammonia equal to that in about 11 cwts. of Peruvian guano; and 1,000 tons of rain-fall, reckoned at 100 tons per head per annum, represent the manurial matter from ten average individuals, and contain ammonia equal to that in about $6\frac{1}{2}$ cwts. of Peruvian guano. In other words, about 1,800 tons of the average metropolitan sewage without, and about 3,000 tons of the average sewage with, rain-fall, &c., would contain nitrogen, reckoned as ammonia, equal to that in 1 ton of Peruvian guano.

31. The value of the total manurial constituents in the sewage, reckoned according to the currently adopted trade prices of the several constituents, taking dry and portable manures as the standard, is nearly exactly indicated by putting a value of 8*d.* on every pound of ammonia, or by giving a value of one farthing per ton for every grain of ammonia per gallon of the sewage. But this theoretical value, according to composition and the trade prices of the constituents, cannot, of course, be taken as directly indicating the value realised or realisable by the agricultural utilisation, in various ways, of sewage of different strengths.

32. * * * * * * *

In regard to the composition of the *drainage*-water of Rugby—

33. Analyses of the drainage-water passing from the experimentally sewaged land at Rugby, showed that those constituents which are of most value, because the most liable to become relatively exhausted, were the most efficiently retained by the soil; but that the drainage-water still contained a considerable portion of valuable manurial matters, besides a large quantity of other substances less important as manures, but affecting the purity of the water.

34. When large quantities of sewage are applied to grass land, the arrangements should be such as to allow of the water being used more than once, so that both the utilisation and the purification of the sewage [and purity of the drainage after the utilisation of the sewage] should be as complete as possible.

In reference to the chemical composition of the unsewaged and sewaged grass—

35. The sewaged meadow grass, as cut and given to the animals, contained a less proportion of dry or solid substance than the unsewaged; and the grass cut during the later portions of the season (both unsewaged and sewaged), contained less solid matter than that cut during the more genial periods of growth.

36. Italian rye-grass, in the condition as cut, was also found to be more succulent, and to contain less solid matter, when grown with sewage than without it; but the proportion of dry substance diminished less as the season advanced, in its case, than in that of meadow grass.

37. The proportion of nitrogenous substance (and also of impure waxy or fatty matter) was much greater in the solid matter of the sewaged, than in that of the unsewaged grass. The proportion of nitrogenous substance was also much higher in the solid matter of the grass grown towards the end than earlier in the season. The proportion of indigestible woody fibre was much about the same in the dry substance of the unsewaged and of the sewaged grass. It progressively diminished as the season advanced; and was generally lower in the dry substance of the Italian rye-grass than in that of meadow grass.

38. A given amount of the dry substance of grass grown in a cold and wet season, or during the cold and wet periods of the year, generally contained more nitrogenous substance, but is less productive than that of grass grown in more genial weather.

39. The greater productiveness of milk, and increase of a given amount of the solid matter of the sewaged grass, appears to depend more on a favourable condition of maturation, digestibility, and assimilability of the constituents, than on the actual per-centage amount of those determined, and previously enumerated.

In regard to the effects of sewage on the mixed herbage of grass land—

40. The effect of sewage irrigation on the mixed herbage of grass land, is to develop the *graminaceous* plants chiefly, nearly to exclude the *leguminous*, and to reduce the prevalence of miscellaneous or weedy plants, but much to encourage individual species.

41. Among grasses which have been observed to be the most encouraged by sewage (according to the locality or other circumstances), are rough meadow grass, couch grass, rough cock's-foot, woolly soft grass, and perennial rye-grass; two or three only remaining, in any considerable proportion, after sewage has been liberally applied for some years.

42. The produce of sewage irrigated meadows being generally cut or grazed when very young, the tendency which the great luxuriance of a few very free-growing grasses has to give a coarse and stemmy later growth, is not an objection as in the case of meadows left for hay; a given weight of the dry or solid substance of the more simple sewaged grass being, when consumed green, more productive than an equal weight of that of the more complete unsewaged herbage.

In reference to the milk from the unsewaged and sewaged grasses—

43. Although more milk was obtained from

a given weight of the dry or solid substance of sewaged than of unsewaged grass, there was comparatively little difference in the composition or richness of the milk from the two kinds of grass. That from the sewaged grass was, however, slightly the less rich, containing somewhat less caseine, butter, sugar, and total solid matter (although more mineral matter), than that from the unsewaged.*

44. When oil-cake was given with the grass (whether sewaged or unsewaged), the richness of the milk was notably increased.

In regard to the results obtained on the application of sewage to oats—

45. In an experiment with oats, in which $135\frac{1}{2}$ tons of sewage were applied per acre, the gross value of the increased produce amounted to more than 5*d.* per ton of the sewage employed, or to about three times the market value of the constituents of the sewage, supposing them to have been extracted and dried; and, in another experiment, in which 510 tons were applied per acre, the gross value of the increased produce amounted to about $1\frac{1}{2}$*d.* per ton of the sewage employed.

46. In the experiment with the smaller quantity of sewage, the supply of water was equivalent to something under an additional $1\frac{1}{2}$ inch of rain-fall at the critical period of growth; and in that with the larger amount, to about 5 inches, which proved to be a great excess at the period of the season at which it was applied, there being an over-production of straw, and the crop being much laid. But experiments were made in the unusually productive season of 1863, and with sewage of about double the average strength of that of the metropolis, that was applied during a period of very dry weather. It is obvious, therefore, that the results were quite exceptional, and cannot be taken as indicating what might be expected from the application of small quantities of sewage to corn crops on different soils, and on the average of seasons.

47. It is probable that 500 tons of sewage per acre is more than would be appropriate to arable land, otherwise treated in the ordinary way, taking the average of soils and seasons; and it is certainly more than would be appropriate for heavy lands, and for wet seasons.

With these remarks we conclude reference to the results of the experiments conducted at Rugby, Croydon, Leicester, &c., &c. Generally, however, it may be observed, that whilst irrigation, either of water or sewage, may have exceedingly variable results in our climate, in those of Europe that are further south, water irrigation becomes not only desirable, but frequently necessary, owing in part to the peculiar porous constitution of the land, to the heat of the climate causing rapid evaporation, and for other reasons. We have already noticed the natural irrigation of the Nile as typical of numerous and similar cases in many parts of the world, but especially in hot climates. China is an eminent example of what may be done in extending artificially the benefits of rivers flowing through, and occasionally overflowing, the land; and in most parts of the fertile plains of Asia and South America, with many parts of the south of the United States, the West Indies, &c., the most beneficial results to all kinds of crops are thus ensured.

* See analysis and remarks on this at page 399, *ante.*

The excreta of man and animals have, as has been pointed out, all the elements necessary for the growth of the plant (see *ante*, p. 393); and hence, if collected in such a form as would permit, at least as far as human excreta are concerned, of their use on the field, nothing more would be required to produce their fertility, as far as manures go. As Liebig observes, "It is clear that if these elements were collected without loss, and every year restored to the fields, these would then retain their power to furnish, every year to the cities, the same quantity of corn and meat; and it is equally clear, that if the fields do not receive back these elements, agriculture must gradually cease."

Of course, in the preceding quotation, the amount of mineral matter retained in the bodies of animals has not been noticed. Such is permanently kept from the soil until the death of the animal. Still the broad principle urged by Liebig is absolutely true, and universally applicable.

But we have also seen, by the extended notice that has been given of attempts to utilise town sewage—that is, the fæces, urine, &c., of the inhabitants—how great a dilution it suffers by a variety of causes. This dilution renders the metropolitan sewage, at the highest estimate, as not worth more than 2*d.* per ton; and, more probably, taking an average of the year round, 1*d.* per ton would be nearest the truth. Referring to p. 414, *ante*, it will be noticed that 1,000 tons of that sewage is equal, in value per annum, to that of the excreta of ten average-sized individuals, or $6\frac{1}{2}$ cwts. of Peruvian guano. Still there is in the sewage the valuable ammonia, phosphates, &c.; and under some circumstances, but especially on grass land, it may be turned to account by gravitating irrigation.

Assuming that it would never pay, commercially, to pump sewage to such a level as would make it available generally to farmers residing within moderate distances of the town producing it, there is still the sanitary aspect. On each side of the Thames, for example, it has been found necessary to inaugurate an entirely new and most comprehensive system of drainage, that has been effected at a cost of between £4,000,000 and £5,000,000 of money. Yet, with this enormous expenditure, the sewage is, after all, cast into the Thames as waste; and, with few and trifling exceptions, the same occurs throughout our islands. But, in every town, great expense is incurred in maintaining the health of the inhabitants by getting rid of the sewage into adjacent rivers. A portion of the money, if spent on lifting the sewage to a moderate height, and then allowing it thence to descend, by gravity, to adjacent farm lands, would have two advantages. Although a source of expense to the town, still there would be a

partial return of it by the payment of 1*d.* per ton by the farmer; and, again, there would be a great production, at least, of grass, and consequent reduction of the price of that article consumed by the animals of the town; and therefore, if a moderate rate were imposed on the occupiers, it is far more than probable that the total loss would be really trifling.

The sanitary effect would be great; and this is a point of extreme importance. Government has already taken partial action in stopping the ingress of sewage matter into some of the rivers whence the water-supply of the metropolis and other places is derived. Under such circumstances, some provision must either be made for the removal entirely, or utilisation of the sewage.

Many attempts have been made at deodorising sewage matter in such a manner that, after this has been effected, the remaining liquid may be allowed to flow into the adjacent river without chance of injury to the fish, or human beings thence drawing their water-supply. Out of the numerous methods that we have examined, none gave such excellent results as that of making the land the deodoriser. We have stood scores of times on the sea-side of the Craigentinny meadows (see *ante*, p. 406), with the wind blowing over them to the sea, and never could perceive the slightest smell, although the sewage of Edinburgh was flowing through them in tons. Yet, on the other side, before the sewage got on to the land, the stench was intolerable.

Again, referring to p. 402, *ante*, it will be found that the results of the action of the land on the sewage are astonishing. The analysis there given, respectively, of the sewage and drainage, shows that, whilst the matter in solution of the sewage was, by the action of the land, diminished from 55·31 to 47·80 per cent., that held in suspension was entirely removed by the land, whether organic or mineral.

Now it is the suspended matter that is the most dangerous to health; for it is that portion of the sewage that is subject to decomposition, and undergoes decomposition, to the contamination of the atmosphere, and the injury of health.

To so great an extent did the sewage impregnate the atmosphere of the banks of the Thames during the hot summers of a few years past, that immense quantities of lime, &c., had to be daily cast into that stream between Westminster and London bridges; but, after all, the result was but a trifling palliation of the evil. If, instead of thus attempting to partially cure, prevention had been adopted, the results would have been more satisfactory.

In a report presented to parliament some time ago, it was recommended that, where the sewage could not be easily got rid of on land, deodorising should be had recourse to. In such cases, although "the value of the solid portions of the sewage was small, and all attempts to realise profit from its preparation as manure had failed, still, mixed with the sweepings and other dry refuse of towns, a ready sale was found for it at from 2*s.* to 3*s.* per ton, which is sufficient to pay a large proportion of the necessary working expenses for preventing nuisance." It was also found, "that the cost of the operation has, in various instances, ranged from ½*d.* to 3*d.* per head of the population per annum, including interest on the outlay. There can, *therefore, be no difficulty, on the ground of expense*, in requiring the adoption of adequate means for the removal of a nuisance in every case in which injury or inconvenience is shown to arise."

But it is added, "that the most beneficial and most profitable method of disposing of sewage, where circumstances will admit this use of it, is by direct application in the liquid form to land. Where such application can only be conveniently effected near habitations, it may be desirable to employ some deodorising agent; *but usually, if proper arrangements are made for conveying sewage on the land, this expense need not be incurred.*"

It is thus evident, that while neither the town nor the farmer can separately turn the sewage to a profit, combinedly they may at least effect great sanitary improvement in, and increased crops outside of the town, at but little loss. A very moderate rate of a few pence per head per annum would thus confer great local benefit both to health and land.

We have largely extended this article on the choice and management of manures, their chemical composition, and other characters, and on the question of the utilisation of the sewage of towns, because the importance of each of these points cannot be exaggerated.

A farmer is in the condition of one who has millions on millions of mouths to feed; we do not mean human beings, but the plants of all kinds that he grows on his farm. If he sow the seed in the wrong soil, or add to that soil unfit food, he may look for a bountiful harvest in vain. Despite all the natural advantages his farm may possess, of aspect, climate, temperature, rain-fall, &c., still, if he have not every condition of success present in the soil, in vain may the rain of heaven fall, the dew settle, or the sun shine; for his plant will seek for the food it wants; and if one necessary be absent, all are nearly valueless beyond a certain limit.

Referring to the words of Dr. Anderson, at p. 388, *ante*—"We can only maintain the fertility of the soil by returning to it *all* the substances which the crop removes, and we can increase it by applying these in larger quantities; *but when the mixture supplied is deficient in any one substance, it does not prevent, but hastens exhaustion.*"

Now the whole of what has been said, from the page just referred to up to the present one, has been intended to show what a soil or crop requires, what each manure presents to supply that requirement, with suggestions as to the best manner in which that can be done. How far we have succeeded in laying the leading facts before the practical man, we know not; but, however plainly and extendedly this has been done in words, they will be of little use unless the suggestion or advice be followed by experiment—first, to verify what has been said, and

next to suit such advice, &c., to the local conditions in which any one individual may be placed. For example, if the farmer comes to the conclusion that sewage is excellent for his purpose, and deluges his stiff clay land with it, he had better bid good-bye to scientific study; for he would commence a habit of vainly adapting a means to an end under conditions that would render success impossible. We repeat, in other words, what was before hinted at in p. 386, *ante*. However excellent scientific advice, analysis, &c., may be, it is only given for *general use* in such a form as the present; and the agriculturist must either exercise his own scientific knowledge, or have recourse to a competent professional person, to make such advice of special use. Thus, if a large volume of good sewage pass alternately through sandy, loamy, and clayey soils, the two former, under the limitations already laid down, will become greatly benefited; the clayey soil will pass from bad to worse: whilst the former two allow of the ready percolation of the liquid, the clay is less porous than a common brick.

It is therefore absolutely essential, to make any practical use of what has been said, that all the conditions of any particular kind of land should be first discovered, and then carefully studied. We have seen that chalk itself, whilst an excellent manure, is a most unfertile soil *by itself;* but, in the condition of marl—that is, mixed with clay and sand—it becomes the most fruitful of all soils. Silica, again, in the form of the sand on the sea-shore, is incapable of producing barely a blade of the coarsest grass, and yet it is a most essential constituent of soils, forming from 42 to 75 per cent. of the richest soils on the face of the earth.

In the same manner we might trace the relation of manures to soils, and of soils to crops; but as this has been already done in very minute detail, we merely need here mention it as one of the conditions of success to the farmer. So far as we have traced the connection of science to agriculture, it must have been perceived that there is no art in which experimental philosophy is so largely involved. Not alone chemistry, but geology, botany, meteorology, climatology, and many branches of natural philosophy, are matters of constant requirement in the proper management of the farm; for as science is only a systematic and experimental investigation into the laws of nature—defining, explaining, and enforcing them—it follows that, in any occupation involving the action or influence of natural laws, an ignorance of them, except by the merest chance, must lead to failure, disappointment, and possible ruin.

The following tables will be understood, in their relation to the preceding matter, by attending to the reference page given on each.

We may here perhaps, profitably both to the farmer and the town councillor, give the following advice in reference to the utilisation of sewage, quoted from an eminent authority.

"Sewage irrigation may be carried on over the same ground for an indefinite period, as is proved by some land near Edinburgh, that has been regularly thus irrigated for upwards of two centuries.

"No known or tried form of precipitating sewage, so as to obtain a portable solid manure, has ever been made to pay in Great Britain.

* * * * *

"Sewage is continuously produced, and should be as continuously utilised. This will be accomplished most easily and cheaply by having at command a proper proportion of land to act as a filter. Sand, gravel, or combinations of sand, gravel, and loam, form the best natural filter. Heavy clay lands should be avoided, excepting for moderate irrigation.

"It will cost more capital, in plant and in labour, to manipulate 500 tons of sewage over ten acres by cast-iron pipes, hydrants, and hose and jet, than to utilise 5,000 tons on one acre by open carriers.

"Sewage is not equally rich at all times of the twenty-four hours. In sewers which regularly discharge fresh sewage, as at Carlisle, and at all towns sewered on true principles, night sewage and day sewage differ materially. At Carlisle, analyses have shown, that from ten o'clock P.M., to eight o'clock A.M., discharge from the outlet sewer is almost entirely subsoil water. There is, as might be expected, an increase in volume and strength in the morning, about nine o'clock; at noon; and again from six to eight o'clock P.M. In Carlisle, Wigan, and Swansea, with 35,000 inhabitants each, and with some 6,000 houses drained, there is no expenditure below the surface in the sewers to remove solids. The daily flow of water is sufficient to preserve the sewer clean. * * * *

"The only safe mode of disposing of town sewage is to filter it through land. The agricultural value will depend on local contingencies. Where conditions are favourable, and works are cheap and economically managed, the application of sewage for agricultural uses will pay. Where conditions are not favourable, *a small rate in aid may be required, as at present in the case of many towns, to enable local authorities to dispose of cesspool and cesspit matters.* Rivers should be dealt with as a whole, and not, as at present, in detail."

TABLE I.

Amount of Green Grass obtained during each separate Month.

......	Green Grass per Acre.							
	Five-acre Field.				Ten-acre Field (half).			
	Without Sewage.	With Sewage.			Without Sewage.	With Sewage.		
	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 1.	Plot 2.	Plot 3.	Plot 4.
	First Season, 1861.							
	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.
May.........	... ...	... ...	... ...	1 9 3 14	... ...	0 14 0 20	1 4 0 10	2 5 0 0
June.........	3 2 3 27	4 17 0 14	7 19 1 23	8 14 3 8	4 10 1 1	4 11 2 8	5 4 1 7	8 16 1 7
July.........	3 1 0 8	2 8 0 15	4 6 0 26	6 14 0 13	0 8 1 18	5 5 1 2	5 8 0 19	1 16 3 24
August......	... ...	3 16 2 23	4 12 2 8	5 19 2 24	1 6 3 9	0 10 2 26	4 12 1 1	5 4 2 7
September..	2 2 2 8	1 3 0 12	6 5 1 7	5 0 0 5	2 3 2 7	0 11 0 13	1 15 0 3	4 16 2 0
October ...	0 19 0 18	2 11 3 0	0 8 0 24	0 16 0 23	0 9 0 8	3 19 1 15	4 0 3 7	3 6 0 2
November..	... ...	... ...	3 9 1 6	4 2 0 5	... ...	... ...	... ...	... ...
December..	... ...	... ...	... ...	... ...	... ...	0 4 0 2	0 7 3 21	0 8 2 0
Totals ...	9 5 3 5	14 16 3 8	27 1 0 10	32 16 3 8	8 18 0 15	15 16 3 2	22 15 2 12	26 13 3 12
	Second Season, 1862.							
May.........	... ...	0 19 1 19	9 15 3 9	8 7 3 6	0 17 1 16	1 14 0 5	11 13 2 7	8 14 0 21
June.........	0 8 1 26	5 10 0 10	5 16 0 26	5 15 1 15	7 10 2 11	15 0 0 3	2 7 2 20	1 15 1 7
July.........	3 16 0 23	8 2 3 3	... ...	4 19 1 19	2 11 2 0	0 8 2 24	6 9 3 6	8 16 1 2
August......	2 8 2 10	4 16 2 16	9 12 0 25	2 0 2 24	0 11 3 0	6 12 1 3	... ...	2 15 3 8
September..	... ...	4 0 1 10	6 12 2 10	9 15 0 0	3 8 0 17	0 16 0 8	9 16 1 22	6 2 2 12
October ...	1 10 0 7	4 8 3 16	2 13 1 5	1 11 1 14	... ...	3 0 0 5	1 14 3 15	3 8 0 26
November..	... ...	... ...	... ...	... ...	1 10 3 9	... ...	... ...	... ...
Totals ...	8 3 1 10	27 18 0 18	34 10 0 19	32 9 2 22	16 10 0 25	27 11 0 20	32 2 1 14	31 12 1 20
	Third Season, 1863.							
April	... ...	... ...	... ...	3 16 3 12	... ...	... ...	... ...	3 14 3 0
May.........	... ...	4 9 1 25	12 4 3 18	6 0 0 15	... ...	... ...	9 0 0 24	4 7 2 27
June.........	... ...	6 4 3 3	3 9 2 20	10 13 2 0	3 7 3 25	13 1 3 22	5 16 0 22	11 13 2 21
July.........	3 18 3 14	6 7 3 9	5 17 2 2	... ...	2 19 3 27	5 13 0 6	4 15 0 13	0 9 3 12
August......	... ...	... ...	4 2 3 5	7 15 3 16	... ...	... ...	5 14 3 0	7 16 2 14
September..	0 19 3 27	2 7 1 27	6 12 0 23	7 14 0 2	1 12 3 23	6 1 0 2	1 5 1 12	0 12 3 0
October ...	... ...	2 12 1 15	2 5 3 5	0 14 1 20	... ...	... ...	3 9 3 20	5 12 2 3
November..	... ...	0 3 0 16	0 5 2 10	0 5 2 24	... ...	0 9 1 6	0 10 0 5	0 11 2 0
Totals ...	4 18 3 13	22 5 0 11	34 18 1 27	37 0 2 5	8 0 3 19	25 5 1 8	30 11 2 12	34 19 1 21

In the above, the amount of unsewaged grass, and of sewaged, obtained at Rugby, is given for the dates named. In 1861, the supply of sewage was deficient. In 1862 and 1863, the supply each year, per acre, was, for Plot No. 2, 3,000; Plot No. 3, 6,000; and Plot No. 4, 9,000 tons (see p. 395, *et seq.*) The five-acre field was level, and the other was sloping.

Table II.

Per-centages of Dry Substance in the Unsewaged and the Sewaged Grass.

Seasons 1861, 1862, and 1863.

......	Five-acre Field.					Ten-acre Field.				
	Un-sewaged.	Sewaged.			Mean.	Un-sewaged.	Sewaged.			Mean.
	Plot 1.	Plot 2.	Plot 3.	Plot 4.		Plot 1.	Plot 2.	Plot 3.	Plot 4.	
Meadow Grass—First Season, 1861.										
1st Crop .	27·9	30·5	26·9	27·7	28·3	22·0	23·3	21·4	18·4	21·3
2nd Crop .	24·4	19·8	14·2	13·3	17·9	26·9	17·1	15·1	16·1	18·8
3rd Crop .	...	13·4	13·7	12·9	13·3	...	12·6	7·3	14·4	11·4
4th Crop .	...	...	15·4	9·6	12·5	...	16·9	15·1	17·8	16·6
Mean .	26·2	21·2	17·6	15·9	...	24·5	17·5	14·7	16·7	...
Meadow Grass—Second Season, 1862.										
1st Crop .	26·7	22·8	14·4	15·3	19·8	26·9	19·5	13·5	13·1	18·3
2nd Crop .	22·8	14·3	16·4	19·4	18·2	17·9	16·2	19·0	16·7	17·5
3rd Crop .	...	18·2	12·9	14·2	15·1	...	14·5	14·4	15·8	14·9
4th Crop .	...	...	...	...	...	...	...	...	*33·8	33·8
Mean .	24·8	18·4	14·6	16·3	...	22·4	16·4	15·6	15·2	...
Meadow Grass—Third Season, 1863.										
1st Crop .	36·1	21·5	17·6	16·3	22·9	39·8	18·6	20·0	14·6	23·3
2nd Crop .	34·4	18·5	14·9	17·8	21·4	18·2	17·7	16·3	18·8	17·8
3rd Crop .	...	17·7	10·9	17·6	15·4	...	12·4	14·6	15·2	14·1
4th Crop .	...	15·8	13·0	12·3	13·7	...	...	13·9	13·6	13·8
5th Crop .	...	...	...	15·3	15·3	...	...	...	...	...
Mean .	35·3	18·4	14·1	15·9	...	29·0	16·2	16·2	15·6	...

Italian Rye-grass, 1863.

......	Un-sewaged.	Sewaged.		Mean.
	Plot 1.	Plot 2.	Plot 3.	
1st Crop . . .	21·3*			21·3
2nd Crop . .	23·7	18·8	17·5	20·0
3rd Crop . . .	36·4	27·5	18·3	27·4
4th Crop . . .	33·2	13·8	18·9	22·0
5th Crop . . .	19·9	16·8	17·8	18·2
6th Crop . . .	...	18·6	20·4	19·5
	28·3	19·1	18·6	...

The above table gives the per-centage of dry substance—that is, the grass freed from water, as explained at p. 408, *ante*—and has direct reference to the power of increase of live-weight, and amount of milk afforded (see, also, Table I. in reference to the various numbers of the crops).

* All three plots were unsewaged until after the first cutting.

Table III.—*Mean Composition (per cent.) of the Dry Substance of the Grass, without and with Sewage, and in each successive Crop.**

In Seasons 1861, 1862, and 1863.

......	Without and with Sewage.				Each successive Crop.					
	Un-sewaged.	Sewaged.								
	Plot 1.	Plot 2.	Plot 3.	Plot 4.	1st Crop.	2nd Crop.	3rd Crop.	4th Crop.	5th Crop.	6th Crop.
Meadow Grass—First Season, 1861.										
Number of analyses giving the means	5	7	9	9	11	9	7	5		
Nitrogenous substance (N×6·3)	13·08	18·67	18·92	19·78	10·33	18·07	23·76	28·25		
Fatty matter (ether extract)......	3·21	3·54	3·53	3·44	3·01	3·60	3·65	3·84		
Woody fibre	28·80	29·34	30·15	29·13	30·80	28·45	28·50	28·60		
Other non-nitrogenous substances	45·66	37·09	35·94	35·92	47·79	38·28	30·84	24·57		
Mineral matter (ash)...............	9·25	11·36	11·46	11·73	8·07	11·60	13·25	14·74		
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00		
Meadow Grass—Second Season, 1862.										
Number of analyses giving the means	4	6	6	7	11	9	6	1		
Nitrogenous substance (N×6·3)	9·49	15·65	15·70	16·83	11·65	12·70	20·44	18·22		
Fatty matter (ether extract)	2·93	3·81	3·64	3·85	2·82	3·72	4·34	4·42		
Woody fibre	29·80	29·20	29·18	29·86	32·42	29·01	26·69	24·86		
Other non-nitrogenous substances	47·84	40·70	40·50	39·01	44·40	43·87	36·00	38·70		
Mineral matter (ash)...............	9·94	10·64	10·98	10·45	8·71	10·70	12·53	13·80		
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00		
Meadow Grass—Third Season, 1863.										
Number of analyses giving the means	4	7	8	9	8	8	6	5	1	
Nitrogenous substance (N×6·3)	10·31	18·43	20·49	22·38	15·05	16·64	19·88	26·12	32·19	
Fatty matter (ether extract)	4·08	5·04	4·68	4·83	4·79	4·31	5·00	4·93	5·07	
Woody fibre	28·64	26·08	25·62	25·40	26·55	28·07	26·08	23·33	20·51	
Other non-nitrogenous substances	47·29	39·48	37·82	35·79	44·32	39·68	37·05	33·26	29·62	
Mineral matter (ash)...............	9·68	10·97	11·39	11·60	9·29	11·30	11·99	12·36	12·61	
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	
Italian Rye-grass, 1863.										
Number of analyses giving the means	5	5	5		1	3	3	3	3	2
Nitrogenous substance (N×6·3)	12·44	18·78	18·11		12·51	12·86	11·07	16·70	20·91	24·76
Fatty matter (ether extract)......	3·53	4·45	3·85		3·61	3·01	3·28	4·31	4·49	5·13
Woody fibre	24·68	25·51	25·55		17·79	26·95	28·79	27·16	22·64	22·16
Other non-nitrogenous substances	49·21	39·76	41·47		56·59	48·28	48·88	40·87	38·34	33·24
Mineral matter (ash)...............	10·14	11·50	11·02		9·50	8·90	7·98	10·96	13·62	14·71
	100·00	100·00	100·00		100·00	100·00	100·00	100·00	100·00	100·00

* See pp. 408 and 409, *ante*.

TABLE IV.—*Summary of the Weights, Increase (or Loss), and Yield of Milk, of the Cows fed respectively on Unsewaged and Sewaged Meadow Grass, with Oil-cake in Addition.*

SECOND SEASON, 1862.

Cows. Nos.	Weights. May 1.	Weights. Intermediate. May 15.	Weights. May 29.	Weights. June 26.	Weights. Intermediate. July 10.	Weights. July 24.	Weights. Aug. 21.	Weights. Sep. 18.	Weights. Oct. 16.	Increase (or Loss) in Weight.	Yield of Milk. First Week.	Yield of Milk. Last Week.	Yield of Milk. Average of the 24 Weeks.
Three Cows—Unsewaged Grass.*													
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs. oz.*	*lbs. oz.*	*lbs. oz.*
1	945	966	1,042	1,092	1,087	1,090	1,076	1,066	1,058	113	229 1	148 15	183 13
2	976	1,004	1,054	1,093	1,100	1,127	1,170	1,190	1,219	243	193 9	31 10	119 14
3	884	896	948	976	988	1,011	1,012	1,020	1,058	174	241 2	162 7	192 14
Totals .	2,805	2,866	3,044	3,161	3,175	3,228	3,258	3,276	3,335	530	663 12	343 0	...
Averages	935	955	1,015	1,054	1,058	1,076	1,086	1,092	1,112	177	221 4	114 5	165 8
Twelve Cows—Sewaged Grass.													
1	1,143	...	1,178	1,246	1,190	1,192	1,224	1,270	1,288	145	165 2	127 10	143 10
2	1,138	...	1,208	1,262	1,263	1,246	1,237	1,267	1,270	132	179 7	77 11	117 5
3	1,076	...	1,153	1,194	1,204	1,232	1,224	1,288	1,223	147	168 15	66 14	122 14
4	966	...	972	994	983	1,000	973	973	936	– 30	202 7	76 3	131 9
5	1,076	...	1,107	1,158	1,132	1,176	1,158	1,199	1,214	138	177 3	67 0	110 5
6	1,006	...	1,096	1,126	1,118	1,121	1,125	1,150	1,169	163	185 1	127 9	150 14
7†	1,112	...	1,068	1,084	1,099	1,071	1,109	1,106	1,101	– 11	314 3	162 14	220 10
8	723	...	785	797	822	824	834	850	868	145	176 6	128 12	136 7
9	965	...	1,018	1,088	1,082	1,116	1,116	1,232	1,224	259	174 12	118 9	147 3
10	866	...	950	953	918	952	950	960	975	109	245 8	152 0	199 10
11	781	...	835	850	828	854	854	834	830	49	206 3	129 15	154 4
12	984	...	1,090	1,142	1,116	1,162	1,155	1,146	1,098	114	178 0	133 10	145 11
Totals .	11,836	...	12,460	12,894	12,755	12,946	12,979	13,275	13,196	1,360	2,373 3	1,368 11	...
Averages	986	...	1,038	1,075	1,063	1,079	1,082	1,106	1,099	113	197 12	114 1	148 6

* It should be observed, that, from May 1 to May 15, the first crop of unsewaged meadow grass not being ready to cut, the three cows had Italian rye-grass, and for twenty days, from August 9 to August 28, in default of unsewaged grass, they had green clover; but the figures given in the last four columns of this Table relate to the whole period, irrespectively of these unavoidable irregularities.

† The No. 7 cow, put up on May 1, which weighed 1,126 lbs., fell ill, and was replaced on May 20 by another, weighing 1,112 lbs., as above entered; and this latter is, for convenience, adopted as the original weight in the calculations for this Table.

For detailed remarks on this Table refer to p. 398, *ante*.

TABLE V.

Comparative and Average Composition of the Sewage-water collected in the Two Fields.

THIRD SEASON, 1862-'3; NOVEMBER, 1862—OCTOBER, 1863, INCLUSIVE.

GRAINS PER GALLON.

—	1862. November. 5-acre field.	November. 10-acre field.	November. Mean	December. 5-acre field.	December. 10-acre field.	December. Mean	1863. January. 5-acre field.	January. 10-acre field.	January. Mean
Number of Analyses	2	2	4	2	2	4	2	2	4
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
Organic matter. In solution	7·64	7·50	7·57	7·86	7·66	7·76	8·70	9·40	9·05
Organic matter. In suspension	26·85	18·81	22·83	20·32	20·42	20·37	14·45	18·48	16·47
Organic matter. Total	34·49	26·31	30·40	28·18	28·08	28·13	23·15	27·88	25·52
Inorganic matter. In solution	32·38	34·00	33·19	32·60	29·95	31·27	32·55	29·10	30·82
Inorganic matter. In suspension	39·17	22·85	31·01	29·35	26·62	27·99	28·43	29·53	28·98
Inorganic matter. Total	71·55	56·85	64·20	61·95	56·57	59·26	60·98	58·63	59·80
Total in solution	40·02	41·50	40·76	40·46	37·61	39·03	41·25	38·50	39·87
Total in suspension	66·02	41·66	53·84	49·67	47·04	48·36	42·88	48·01	45·45
Total solid matter	106·04	83·16	94·60	90·13	84·65	87·39	84·13	86·51	85·32
Ammonia. In solution	4·88	4·93	4·90	4·03	3·51	3·77	2·09	2·22	2·16
Ammonia. In suspension	2·12	1·68	1·90	1·54	1·34	1·44	1·26	1·30	1·28
Ammonia. Total	7·00	6·61	6·80	5·57	4·85	5·21	3·35	3·52	3·44

—	1863. February. 5-acre field.	February. 10-acre field.	February. Mean	March. 5-acre field.	March. 10-acre field.	March. Mean	April. 5-acre field.	April. 10-acre field.	April. Mean
Number of Analyses	2	2	4	2	2	4	1	1	2
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
Organic matter. In solution	5·90	4·35	5·12	6·80	6·80	6·80	6·80	6·35	6·58
Organic matter. In suspension	19·98	21·95	20·97	24·85	9·15	17·00	22·35	13·75	18·05
Organic matter. Total	25·88	26·30	26·09	31·65	15·95	23·80	29·15	20·10	24·63
Inorganic matter. In solution	29·93	30·83	30·38	33·88	30·55	32·22	32·85	26·20	29·52
Inorganic matter. In suspension	37·10	29·82	33·46	45·40	16·28	30·84	33·25	30·40	31·83
Inorganic matter. Total	67·03	60·65	63·84	79·28	46·83	63·06	66·10	56·60	61·35
Total in solution	35·83	35·18	35·50	40·68	37·35	39·02	39·65	32·55	36·10
Total in suspension	57·08	51·77	54·43	70·25	25·43	47·84	55·60	44·15	49·88
Total solid matter	92·91	86·95	89·93	110·93	62·78	86·86	95·25	76·70	85·98
Ammonia. In solution	3·82	3·85	3·84	5·13	4·89	5·01	4·68	3·41	4·05
Ammonia. In suspension	1·69	1·81	1·75	2·28	0·98	1·63	1·43	1·63	1·53
Ammonia. Total	5·51	5·66	5·59	7·41	5·87	6·64	6·11	5·04	5·58

—	1863. May. 5-acre field.	May. 10-acre field.	May. Mean	June. Mixed; 5 and 10-acre fields.	July. Mixed; 5 and 10-acre fields.	Aug. Mixed; 5 and 10-acre fields.	Sep. Mixed; 5 and 10-acre fields.	Oct. Mixed; 5 and 10-acre fields.	Average for the 12 months in the two fields.
Number of Analyses	2	1	3	2	2	2	2	2	35
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
Organic matter. In solution	7·05	7·50	7·28	7·83	9·05	11·45	8·90	11·40	8·23
Organic matter. In suspension	17·08	20·60	18·84	23·07	29·40	29·35	53·95	44·10	26·20
Organic matter. Total	24·13	28·10	26·12	30·90	38·45	40·80	62·85	55·50	34·43
Inorganic matter. In solution	39·78	42·80	41·29	41·93	44·70	46·30	50·85	53·80	38·86
Inorganic matter. In suspension	22·50	18·50	20·50	33·57	28·60	29·10	93·30	50·10	36·60
Inorganic matter. Total	62·28	61·30	61·79	75·50	73·30	75·40	144·15	103·90	75·46
Total in solution	46·83	50·30	48·57	49·76	53·75	57·75	59·75	65·20	47·09
Total in suspension	39·58	39·10	39·34	56·64	58·00	58·45	147·25	94·20	62·80
Total solid matter	86·41	89·40	87·91	106·40	111·75	116·20	207·00	159·40	109·89
Ammonia. In solution	6·41	6·40	6·41	6·50	6·85	7·11	8·81	9·07	5·70
Ammonia. In suspension	1·14	1·28	1·21	1·70	2·88	2·21	3·54	2·91	2·00
Ammonia. Total	7·55	7·68	7·62	8·20	9·73	9·32	12·35	11·98	7·70

At page 400, *ante*, we have entered into details in respect to the sewage composition of Rugby; at page 403, *ante*, of that of the metropolis; and that of Croydon at page 406, *ante*.

THE MECHANICAL OPERATIONS OF THE FARM.

In the preceding pages we have passed under extended review most of the leading chemical conditions connected with agriculture. Lengthened as the notice of them has been, still our limited space has necessitated the omission of many important particulars. Chemistry applied to agriculture, like its congener, organic chemistry, has expanded its proportions so greatly during the last few years, that it requires a powerful intellect to grapple with either subject in all its details. The number of labourers in both fields has far exceeded that of any other branch of science, or its applications, except, perhaps, electricity and telegraphy; and hence an astonishing mass of facts has been collected, the digestion of which is a matter of no small labour.

Equally so in the mechanical operations of the farm, owing to the extensive adoption of steam and other machines in most branches of in and out-door work, the progress has been as surprising as successful. But comparatively few years have elapsed since the labour of the ox, horse, and man afforded all the motive-power for ploughing, harrowing, sowing, reaping, and threshing. Now the puff of the portable steam-engine may be almost as frequently seen at the farm as on the railway. Machinery, formerly almost exclusively confined to the factory, is now as commonly seen in the field; and the saving of animal labour, together with that of man, an improved method of operation, and a diminution of expense, are but a few of the benefits thus conferred by steam on the farmer.

A great advantage of machine power in any art is the regularity with which operations of all kinds are performed. There is nothing left to chance, but all works by steady rule. Thus, in a well-appointed cotton factory, the thousands of spindles, or hundreds of shuttles at work, are under the most complete control, and move on in the most perfect harmony. Several feet off is the motive-power that sets all in action, itself equally under control by the turning of a little valve. The extension of such method and order in a farm cannot but be of the most important and beneficial consequence, and it certainly has marked a new era in the oldest occupation to which man has put his hand.

A visit to two farms, one in which machinery is employed, and the other where it is absent, will strike the stranger with the great contrast in everything that is carried on; but it is in the daily routine of farm life alone that the full effects of machinery are manifest. At one time a good ploughman justly possessed a kind of monopoly of his labour, and could demand and obtain his own price. Frequently an *attaché* of one farm, his services were so highly valued, that the loan of him was considered an act of grace and condescension by the neighbours. But however excellent in the performance of his duties, he was liable to infirmity, and other hindrances, which made him uncertain. Now, however, by the steam-plough of the best kind, the ploughing of a field has become almost entirely independent of man, and can, with certain limits, be carried on by an ordinary labourer.

Another benefit that the farmer gains from the use of machinery is, that it renders him, a large extent, unaffected by the ever changing supply of labour, to which he was formerly subject. We already have slightly alluded to this, but it deserves further mention. In our uncertain climate, the most bountiful harvest may almost be irreparably ruined in a day or night. At one time, when the fields were clothed with the ripe yellow corn, the farmer had frequently to stand, looking anxiously at it, unable to reap for want of labourers; and running the risk of great loss, and, perhaps, even ruin, from the delay thus forced on him by circumstances over which he had no control. But, by the aid of steam, he can not only reap his harvest speedily, at any time he pleases, but when it is brought into his barns, he can at once thresh and realise his produce.

It is true that some circumstances interfere with the universal application of machinery in the farm; as, for example, peculiarities of soil, inequality of surface, and other causes. But, by persevering ingenuity, all these will doubtless be eventually overcome, for infinitely greater obstacles have been similarly conquered in manufacturing districts, where a far larger amount of ingenuity must be called into play for that purpose, because of the greater intricacy of the machinery there employed.

But it is not only in the farm that the agriculturist has benefited by the extension of machinery. The railway now carries his produce, at almost nominal prices, to any place or market that a telegram indicates it can be best sold at. His implements, formerly made by hand, are now turned out by machinery, and are more serviceable to him than those of old construction. If he have no railway near, the traction-engine, driven by steam-power, will draw almost any load, at a comparatively rapid pace, sparing the wear and tear of horse and ox over bad roads, or in a hilly country. But we must not attempt here to enumerate all the conveniences and advantages thus afforded: they will crop out as we proceed.

We pass on to consider, in detail, some of the most important of farming operations, not directly, but indirectly bearing on chemistry applied to agriculture.

Draining.—The importance of this operation will have been fully perceived by what has been stated in reference to the physical and chemical conditions of the soil, essential to fertility. Owing to a much-increased attention to this operation, the area of our pasturage and arable land has been largely extended. Much, however, as there has been done, a great deal has yet to be effected. For example, in the midland counties, scores of acres are often laid under water for days, if not weeks, together; and grass, hay, and corn are frequently spoilt over great breadths of land.

We have previously pointed out that draining has the effect of "warming" cold soils; or, more philosophically, it should be stated that the cause of the cold of such soils has been removed. In Ireland, the effects of improved drainage have been astonishing. On one large estate, with which we are acquainted, in the west of Ireland, a tract, formerly little better than a marsh, bearing only useless coarse grass, has been converted into fruitful fields, bearing, after two or three years' labour, excellent corn, green, and grass crops.

One reason for draining land effectually, is found in the necessity of a certain temperature to cause the germination and growth of the seed. At p. 365, *ante*, the conditions essential to both have been described. Now, an excess of water on the land tends, partly by evaporation, and partly by conduction, to rob the soil of its natural heat, and also to prevent the heating effects of the sun from having their full influence. It is familiarly known that, in a watered garden running east and west, seed sown on the north side, and consequently having a southern aspect, will germinate and grow rapidly, because the soil is freely exposed to the rays of the sun during the greater portion of the day; whilst on the south side, or that having a northern aspect, the soil being only visited during a brief part of the day by the sun, will remain cold, the moisture in excess keeping down the necessary temperature; the consequence, frequently under such circumstances, is that a fortnight's difference will be seen in the germination, growth, and fruit-production of the two sides. A thermometer, immersed beneath the mould on each side, will frequently show a difference of temperature of 10° Fah.

Precisely the same occurs in undrained ground, although only partly from the same reasons. But, besides the heat-robbing propensity of excess of moisture, another effect follows. It has been shown, that the moment germination commences, chemical changes ensue (see *ante*, p. 365). Now these changes result from the action of the atmospheric oxygen, which oxidises (see *ante*, p. 355) the carbon, &c., constituting the starch of the plant (see *ante*, p. 362), converting it into sugar and carbonic acid. If, therefore, the air is prevented from getting to the seed, together with a due amount of moisture, no growth can go on; and if it do occur, it will be unhealthy and unfruitful. For the same reasons, a thorough ploughing, so as to break up the soil into small fissures, is requisite; and this performs the office of aërating the seed, or the roots of the plant, allowing excess of moisture to drain off, and leaves openings through which the rootlets of the plant can extend in all directions in search of food and moisture (see *ante*, p. 375).

In the application of manures, not excepting even sewage itself, drainage is of high importance. It is to the decomposition of a manure, in every case, that its value is due. First, in the case of mineral solids, solution must be effected. If too much water be present, either the absence of atmospheric air from the constituents will prevent decomposition, essential to the nutrition of the plant, and solution will be stopped; or, if the latter take place, the solution may be so far diluted as to be, comparatively, valueless.

On clay lands, again, the mechanical effects of drainage are surprising. We have seen stiff London clay converted from an unfertile condition to one that bore well by the simple breaking-up of its mass in a natural manner. As a matter of experiment, a short time ago we had several square yards of clay in the north of London, that had never been before brought to light, dug up from a deep hole made for the purposes of the main drainage, and it was made fertile as follows:—It was first exposed, for a week, to the sun in heaps; then broken, as it dried, into small masses. These were alternately watered with an ordinary can, fitted with a rose, and then allowed to dry in the sun. A coarse rake was then used to break the masses up still more; and thus, by a succession of sun-drying, breaking with the rake, and watering, it was brought to the fineness of ordinary garden mould. In this condition it was heaped up in beds eighteen inches wide, and twelve inches higher in the middle than the sides. The operation, as an experiment, was began in March; and, in the summer, say three months and a-half later—this clay, without a particle of manure added, except what was gathered from New River water, had growing on it, and all in flower, scarlet-runners in profusion, major convolvulus, mignonette, tall and dwarf nasturtiums, poppies, sweet peas, calliopsis, mustard, fuchsias, geraniums, musk, sweet William, box, and fir plants—a heterogeneous mixture, but all the fitter to test the value of drainage. That this had caused the astonishing fertility here described, is certain; for, as the experiment was undertaken for the express purpose of relating its result in this work, an opposite condition was induced in another portion of the clay. This was brought to the same fineness as that just described; but, instead of being heaped up, it was laid perfectly level. It had grown only a few scarlet-runners, which were very sickly; but not one of the flowers named as flourishing on the well-drained bed, had grown on it. Comparing the amount of water each side will take daily to moisten both equally, we may add that forty pounds served for the level undrained side once in twenty-four hours; whilst the heaped-up side required watering twice a day, with not less than 200 pounds at each time; and even with this large quantity it was always drier than the other side at the end of the twenty-four hours.

Now, this experiment, which was conducted with every care, as if it had been an analysis in the laboratory—every operation, from first to last, except digging the clay out of the pit, being conducted personally—indicates largely the advantage of thorough draining and breaking up the soil in the most perfect manner possible. The water, either rain or otherwise, that falls on such a surface as we have described, percolates gently, dissolving some of its constituents, and oxidating others. The substances in

solution are carried to the roots, and there are absorbed; whilst the water that has parted with them passes off. We have fully noticed the result of applying sewage, and the rapid and complete exhaustion of its suspended matter, at p. 403, *ante;* where it will be seen that the drainage that passed off from the fields was destitute of any inorganic or organic substance previously held in suspension; whilst those that were held in solution were also in diminished proportion to that found in the sewage.

Precisely similar results will accrue by the application of guano, and all other manure, to well-drained land. The soil, whilst acting as a filter, yet allows of the retention of such matter as may be required for the plant. On the other hand, manures applied to badly or undrained land, on the first heavy fall of rain will be very probably washed off the soil, and taken into the ditch; by which, not only is a large portion of the manure lost, but the chance of a crop, possible under other circumstances, lost.

Another effect of good drainage is perceived in the action it has upon weeds. We have already noticed that the sewage selects certain, and rejects other, grass plants. It was stated, at a previous page, that the general effect of that liquid was to develop graminaceous or grass plants, to the exclusion of others, and especially weeds; rough meadow grass, couch grass, rough cock's-foot, woolly grass, and perennial rye-grass being encouraged in growth; whilst weeds, previously present, were exterminated. This circumstance alone is one of the highest importance to the farmer; for if the weeds get the start of his wheat, or other cereal crops—all of which belong to the *Gramineæ*, or grass tribe —they choke the young plant; and if it has outstripped them in height, they rob it of a portion of the soil and manure that ought to go to its support. We particularly noticed this effect on the two patches of clay ground that were the subjects of our experiment, just previously described. The well-drained patch presented, during the whole time named, but two weeds—groundsel and wild chamomile—only about four plants of the two presenting themselves. On the undrained side there was at least six different species of weeds, and upwards of thirty plants, which, as each was pulled up, was followed by its fellow and successor. Hence, in flat marshy grounds, a great variety of useless weeds are found; whilst, in more naturally or artificially drained soils, such are invariably absent.

It would be apart from the object of this work if we were to enter into any lengthened description of the mechanical department of draining land. We may, however, speak on two points in which science is involved, and which, in practice, we have seen very frequently neglected. The law that liquid always finds a level, is one too often forgotten. A field may be covered with draining-tiles, but if they are not laid with a fall in at least one direction—if some are depressed in hollows, whilst others are raised higher on each side, any expectation of successful drainage would be as sensible as the hope of emptying the sea with a basin. An amusing instance of this came under our notice on the land of a friend some years ago, in the neighbourhood of Glasgow; it was, however, reverse in its character in one sense. He was anxious to drain a pond that had been accumulating for many years on a neighbour's property, and so offered a fair price for the ground, as the subsoil water from this pond percolated into and injured his meadow. So convinced were the neighbouring farmers of the impossibility of draining the little lake, that they seriously questioned the sanity of our friend. But being a thoroughly scientific man, he took levels in the usual manner, and, by taking care to observe the law of fluids that has been just named, succeeded, in a few days, in ridding himself of all the water of the pond. To the eye of a scientific man no difficulty was apparent at a glance; but the neighbouring farmers were so wedded to their own prejudices, that nothing but the sight of the empty pond could convince them of the possibility of the result.

A practice is prevalent in many parts of our islands, of simply digging a trench across a field to one, or between two ditches, and throwing in large and small stones. The land will drain thus for some time; but, eventually, the earth fills up all the pores between the stones, and drainage at once ceases. Similarly, if cylindrical tiles be used of too small diameter, or fixed too far apart, the same result will accrue, and expense be incurred for no purpose.

Ploughing, &c.—The extensive application of machinery in relation to all field operations, has, as we have previously remarked, commenced a new era in the art of farming. Nearly all the field operations are, more or less, carried out by steam-machinery at the present day, as are also many in-door duties. Hence steam-ploughs, reaping, threshing, and other engines have been brought out in a great variety of forms. The Exhibitions of recent years have been notable in respect to agriculture, for the number, variety, and effectiveness of the machines that are brought forward, and worked either by steam or horse-power.

In the introductory portion of this work, we have directed attention to the history of ploughing, and have also given illustrations of ancient and of some modern ploughs. From these it will be seen how much engineering science has done for agriculture. We shall presently enter more fully on this important subject, and illustrate some recent inventions.

The operation of ploughing has for its object the reduction of the soil to a state approaching that of powder, although rarely reached by any of the ordinary methods; of thereby affording a large porous surface, from which the roots of the soil may gather soluble food; and, at the same time, of, to a certain extent, forming surface drains, by which excess of moisture is carried off.

But the chemical results accompanying those of a more mechanical nature just referred to, are those of bringing to the surface, soil and other matters that, in their natural or buried

condition, have no fertilising power; but which, on exposure to air and moisture, become decomposed, and furnish the root of the plant with a variety of nutritive substances. Hence the value of *deep* ploughing, by which fresh or virgin soil is brought to the surface, and exposed to the action of atmospheric influence.

At p. 424, *ante*, we have recounted an example of what may be done with the poorest soil; and have there shown, that a clay buried for ages under ground, may, by proper management, be made as fertile as almost the best ground that has been long under culture. Indeed, within certain limits, the soil that lies beneath that in which crops have been grown, should necessarily be in constant receipt of the substances suitable for plant nutrition. If, for example, a plot be manured, either the subsoil will absorb any excess of the manure, or this will run off into the drain at the side of the field. But even if the farmer be so careless as to allow this latter result to take place, still the subsoil must absorb a certain portion. On being ploughed up, and exposed to the air, it therefore becomes a bank, returning manurial interest and principal. Further, the deeper the ploughing is carried on, the more extensive is the "field" or matrix that is produced for the expansion of the roots of the plant. Just in proportion as this is extended, so does the plant, in the same space of time, acquire more food, and has, by its roots, a firm hold in the soil, making it stronger in the stem, whether of corn crops or grass. Again, with a thin soil, the water drains or evaporates off speedily; and, should the season be dry, the earth becomes parched, whilst the crop is burnt up for want of moisture.

In all the fertile soils there exists a substance already named as *humus*, which arises from the decay of animal and vegetable matter. Its presence largely determines the fertility of a soil, which also depends on the presence of the proper mineral constituents; hence the great use of the leaves of trees, rotted dung, &c., and the compost heap, all of which tend not only to form and afford humus, but also to break up, when mixed with them, the hard mineral substances of the soil.

The humus exists mostly on the surface of a soil: it is constituted of a variety of compounds that we need not here enumerate, as such would be of no practical value to the farmer. But when the soil is ploughed deeply, the mineral constituents destitute of humus, as they are brought to the surface, become mixed with it; and, consequently, the two essentials of the soil are united, ready for the use of the plant.

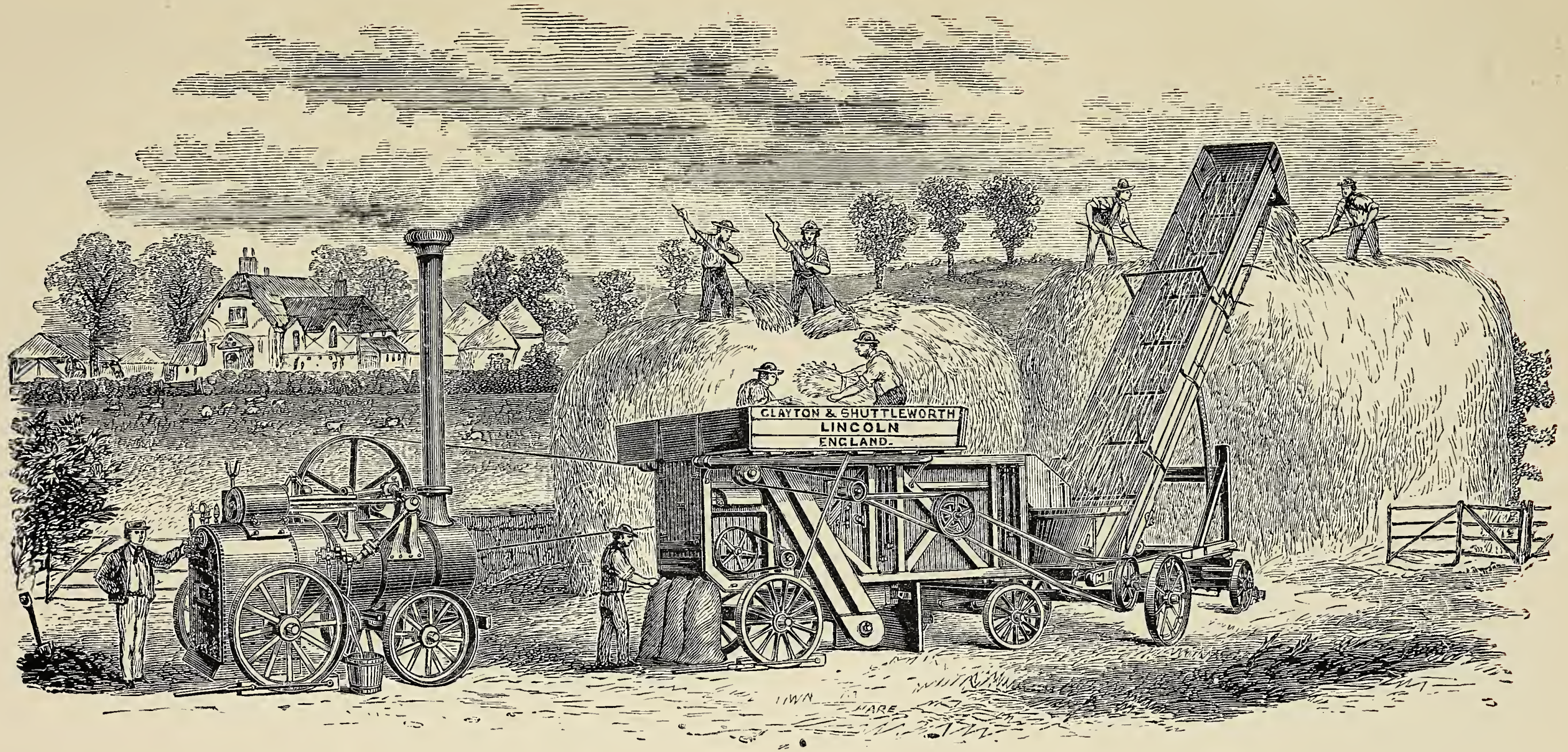
Hence we notice the value of deep ploughing in a chemical point of view; and we next must refer to the advantages of a high state of pulverisation.

We have already shown that the more porous the soil, the greater chance has the plant of expanding its rootlets in all directions in search of food and moisture; it hence follows, that a highly pulverised soil, suitable to any crop, will be more useful than one which is composed of coarse lumps. At one time it was thought that there was a limit to the extent to which pulverisation should be carried, because of the probable loss that might be sustained by the washing away or solution of the valuable parts of the manure, and other constituents of the soil. But a reference to p. 403, *ante*, will show that no such danger exists. It will be there seen that *all* the suspended matter of the sewage was absorbed by the soil, and that none of it was contained in the drainage-water that resulted from the application of the sewage at Rugby. The results of experiments with sewage at Croydon were similar, and are detailed at p. 406, *ante*. Indeed, the more completely the soil is pulverised, the more fully it exerts its absorbent and retentive powers in respect to nutritive matter. Some of the richest soil in the world is characterised by great porosity and fineness, having been gradually deposited as highly pulverulent matter; instances of which are given in respect to alluvial beds of soil, as of the Nile, &c., at p. 352, *ante*, and the extensive beds found in Central Asia.

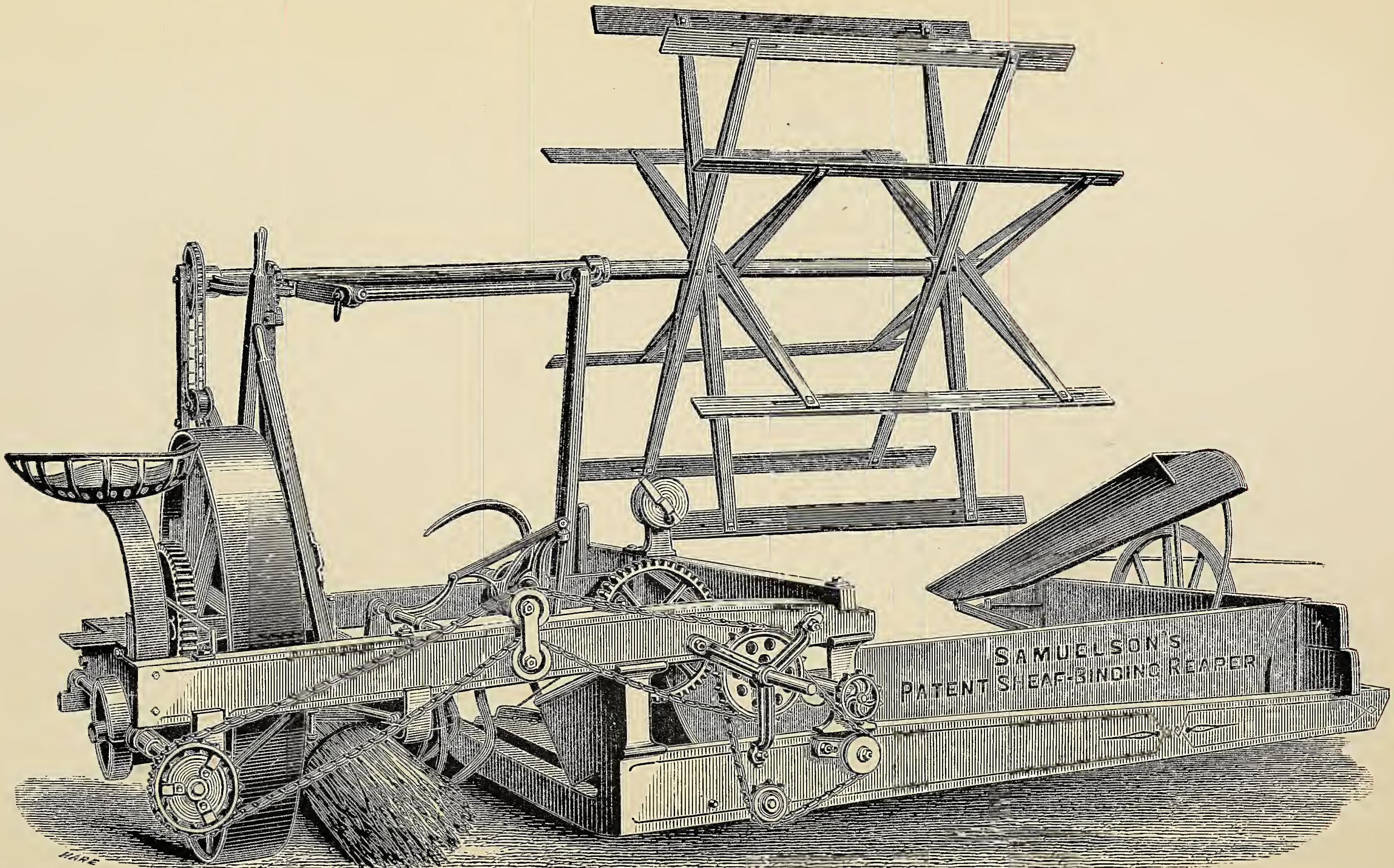
Nature teaches us precisely the same facts and principles. On the surface of the bare rock, perhaps, not a moss nor lichen will grow. If, however, there be a crack or crevice in the rock, a fern or piece of grass will soon make its appearance; and as soon as atmospheric action and that of moisture disintegrates the rock, the amount and size of the herbage will increase, until, at last, a tree will find sufficient nutriment. Hence one of the most refractory of all rocks—the trap—does, by this gradual progress of disintegration, become the bed in which some large oaks, elms, &c., frequently grow luxuriantly.

A large proportion of the barren parts of our islands is due to the shallow condition of the soil; yet we have seen oats, &c., growing in Scotland, on soil so shallow that the wheels of a phæton have penetrated through it to the subjacent limestone rock. On many of our marshes precisely the same thing occurs; the surface soil is so thin, and the subsoil too resisting to permit of the growth of anything but the poorest grass, rush, or weed. Yet, when deep ploughing, good pulverisation, aided by manure, is had recourse to, the same ground will become eminently fertile, as is well illustrated in many parts of Lincolnshire, and adjacent fenny counties, where well drained.

It is evident, again, that a state of powder, or pulverisation, is that condition essential to plant growth; because the roots require abundant passage in all directions in search of food, and, therefore, the deeper the ploughing, and the more complete the pulverisation, the fuller and quicker will be the assimilation of inorganic and organic matter. At p. 424, *ante*, whilst recording the experiments we made with crude London clay, this fact was shown to be of the highest importance; for where a shallow unbroken soil of clay was experimented on, infertility was the result; whilst the opposite was obtained in the case of the finely pulverised clay. That description was penned during exceedingly dry weather;



RICK-MAKING MACHINE.



SHEAF-BINDING REAPER.

now, whilst these lines are being written, a tremendous storm of wind and rain is raging, and has been for twelve hours. The unbroken clay is swamped with water; but that which has been highly pulverised shows not the slightest sign of water, except by having had its colour changed—not a pool the size of a teaspoon appearing on it.

Another point of importance that may be mentioned, is the capillary action of finely pulverised soils; and a few words of explanation will be here required in reference to the term *capillary*. If tubes of glass, of exceedingly small bore, be placed in water, upright, so that one end shall be immersed in the fluid; or if two pieces of window-glass be so placed in water that they touch at one edge, whilst they are apart at the other, then the water will rise higher than its level in the tubes, or between the window-glass pieces, and highest where the distance of the surfaces of the glass is but small. Precisely the same happens when a lump of loaf-sugar is rested in a saucer containing a little water; for, as is well known, the liquid rapidly rises up and moistens the sugar in every part. The attraction which causes this is called *capillary*, or hair-like, from the Latin word *Capillus*, a hair, or fine tube.

In highly pulverised soil the capillary attraction acts; and the greater the condition of pulverisation, so does the amount of that force exert itself, for precisely the same reason that the finest bore-tubes, or the nearest approximation of the glass, causes the water to rise the highest beyond its natural level. Now, in the soil, the fine pores it contains cause sublying moisture gradually to rise to the roots; supplying them with water in the dryest of seasons, in all ordinary circumstances in temperate climates. Hence we notice an additional and highly important reason for deep ploughing and great pulverisation.

There are numerous other advantages which these two latter methods of treating the soil give rise to. A fine soil rapidly absorbs both heat and moisture from the sun and the atmosphere, encouraging the two leading conditions of germination and growth. Even in the absence of rain, the great radiating power of such a soil has, within certain limits, beneficial uses; for being promotive of evaporation, more dew would be deposited on its surface at night, than would be on the same soil in lumps or masses. The reason of this will be apparent by reference to p. 365, *ante*, where, amongst the *physical conditions* of agriculture, we have drawn special attention to the general effects of heat, and its chief laws.

But whilst the advantages of the fine soil are seen in its power of attracting and retaining moisture, it has also the advantage of allowing excess of moisture to pass off by draining; so that whilst keeping a certain amount of water, it parts freely with it if the liquid be too largely present. The best natural illustration of this may be found in the sand of the sea-shore, which is scarcely wetted by the wave before it ceases to present the appearance of water on its surface, except by acquiring a somewhat darker colour.

We may next draw attention to some of the most approved and generally used inventions, which have replaced, to a greater or less extent, human labour on the farm. In the introduction, p. xxi to xxiv, various forms of agricultural implements have been illustrated, including a subsoil plough, constructed by Messrs. Burrell and Sons, of Thetford, a patent balance plough, a steam harrow, and an agricultural locomotive engine; and at p. xxiv a traction and agricultural steam engine, all by the same makers.

Fig. 323 represents a patent traction engine, constructed by Messrs. Clayton and Shuttleworth, of Lincoln. It can be used for driving portable machines, which have frequently to be moved from place to place, such as threshing machines let out on hire, steam ploughing tackle, &c., as well as for the transport of heavy loads in preference to using horses.

In Fig. 324 is a representation of a portable steam-engine constructed by the same makers. It is intended as a means of power for carrying on all the home work of the farm, such as threshing, &c., &c. It is recommended on account of its simplicity and durability, the quality of materials, economy in regard to the use of fuel and little necessity for repairs. The engines are of suitable dimensions for developing more than double their nominal power while running at a moderate speed. And the boilers of the engine will evaporate sufficient steam for developing three times the nominal power, if requisite, without excessive stoking.

Among other mechanical arrangements constructed by the same firm may be named a Portable Steam Threshing and Stacking Machine, one of which is illustrated among the folio cuts of this work.

We have been favoured by Messrs. Samuelson & Co., of Banbury, with several illustrations of their agricultural machines. One of them is given as a folio plate showing the construction of their patent Sheaf-Binding Reaper.

Messrs. Samuelson & Co.. of Banbury are, we believe, the first to introduce into this country a Self-Binding Reaper, wherein the binding operation is performed on a level with, and virtually, on the platform itself; the advantages of this arrangement will be easily understood, as it obviates the employment of canvas, elevators or belts, which are more or less affected by climate, and if left out in the wet soon become damaged or destroyed. The absence of elevators, and consequent lessening of friction, also contribute a corresponding decrease in the draught. As will be seen from the illustration the machine is exceedingly simple in its arrangement, and notwithstanding its simplicity, all its various parts, we are informed, are designed to give the greatest amount of strength and durability; every advantage is taken of reducing friction. The whole machine is said to be lighter in dead weight than any other Self-Binder. The position of the driver, when seated, is such that he can easily operate the machine, and have his work well

before his eyes, thus getting the whole under his perfect control. Without leaving his seat he can instantly tilt the fingers, raise and lower the gathering reel, or adjust the Binder to suit long or short straw. Thus it will be seen the machine is designed to cut any crop, however it may vary in growth, or in length of straw. The sheaves can be delivered at equal intervals, or their size may be regulated as desired by the driver. The Binding device appears simple and effective. The material used for binding the sheaves being wire. The illustration is a back view of the Binder. The standing corn or grain is brought into contact with the knife, and falls upon the platform by the aid of the gathering-reel; through the platform project a series of tines or stucks, fixed upon endless chains, which convey the cut corn to the Binding apparatus; the sheaf is allowed to drop gently to the ground, between the platform and the travelling wheel; this low drop of only a few inches is an obvious advantage where the grain has become over ripe and is liable to shed. This feature alone is one which the patentees claim as a desi-

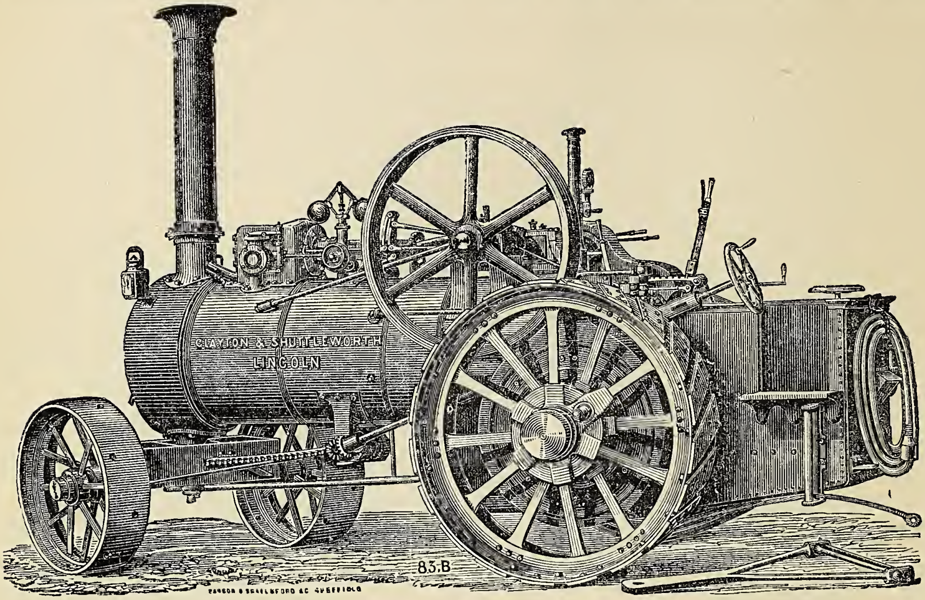


Fig. 323.—Patent Traction Engine.

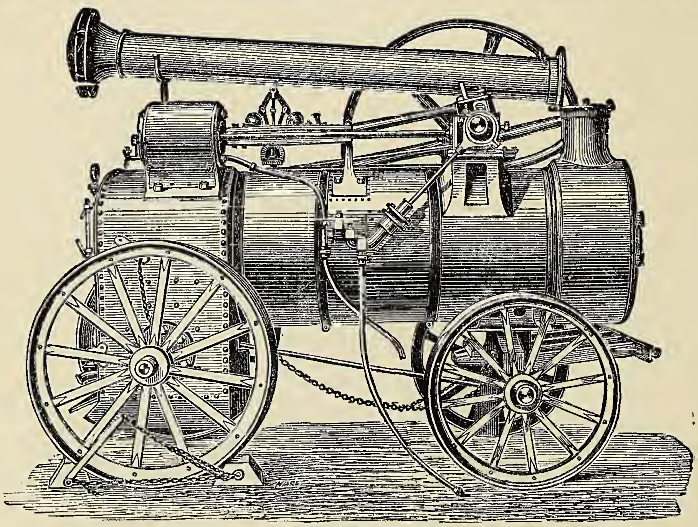


Fig. 324.—Patent Portable Steam Engine, for use on the farm.

deratum which cannot be attained in any other known forms of Self-Binding Reaping Machines.

Fig. 325 represents a one-horse reaper constructed by the same firm.

We are indebted to Messrs. Samuelson also for the following illustrations :—Fig. 326, their patent "Original" Self-raking Reaping Machine; Fig. 327, their "Gem" Balance-draught Grass Mower; and Fig. 328, their Balance-draught Combined Mower and Reaper.

Messrs. Burrell and Sons, of Thetford, Norfolk, have favoured us with the following illustrations of some of the Agricultural Machines of their manufacture. As already mentioned, some of their engines have been already illustrated in this work, viz., a Traction Engine at page xxiv. (Introduction), and one on page xxiii.; a Sub-soil Plough at page xxii., and a Balance Plough at page xxii. Fig. 329 represents their Patent Universal Engine for varieties of work in the field.

Fig. 330 represents a Combined Threshing, Dressing, and Finishing Machine. It will produce a perfectly uniform sample of full-sized grain free from tail corn.

Fig. 331 represents Messrs. Burrell's Patent Turning Cultivator. This implement is adapted to be worked by all systems of Steam Cultivating Machinery. It consists of a strong iron frame, carrying, according to circumstances, from 5 to 13 tynes, and resting on three road wheels, the front wheel being the steering wheel. The axle of the two hind wheels is cranked, so that by its being turned, the frame is lowered or raised, and by these means the depth of the tynes adjusted. The long end of a draft bar, or "patent turning lever," is provided with two arms, to which the two ends of the ropes are attached. The arms are set at an angle, for keeping the tail rope clear of the implement. The lever itself is held by a vertical stud fixed to the frames, considerably behind the steering wheel. The position of the draft-stud (the subject of a special and important patent) gives the necessary liberty and power to the steering wheel, and enables it to lead the implement at almost any angle out of the line of the pulling rope. On the short end of the turning lever is a chain communicating with a quadrant on the crank axle, and as the lever is pulled round, the chain, acting on the quadrant, turns the axle, lifts the frame, and raises the tynes out of the ground. The plan of operation is as follows:—As soon as the Cultivator is brought up to the headland, the reverse pull brings the lever round and lifts the tynes out of the ground, and they are held up by a catch; when lifted the required height, the lever strikes against a stop and the implement turns into new ground; the man (who never leaves his seat) releases the catch, the tynes drop into the ground, and the implement is drawn across the field.

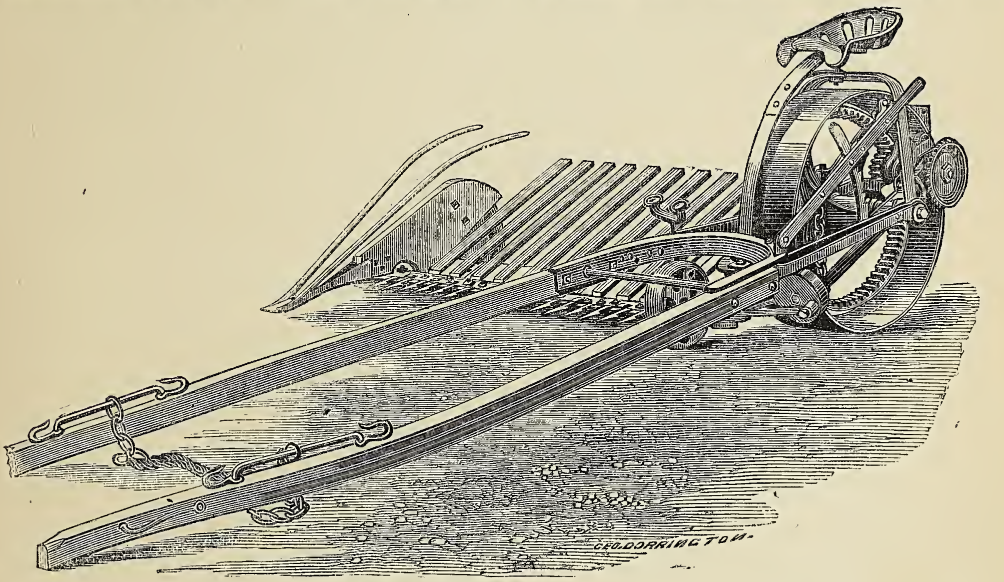


Fig. 325.—One-horse Reaper.

The principal advantages of this excellent implement are as follows:—Its size is only limited by the power of the engines, which thus may be used to their utmost capacity. It smashes up the soil, working steadily, and always preserving a perfectly uniform depth. Even the largest implements of this description require only one man in attendance. In turning round, no additional work whatever is required, and scarcely any time is lost, whilst the implement, however wide, at once moves into new land, leaving small and regular headlands. On average soil 30 to 50 acres per day may be efficiently cultivated. Ridging bodies attached to the frame of this Cultivator make an

effective and easily-handled ridging implement. The ridging bodies are attached without taking away the tynes, and both operations are done at the same time.

This implement is well suited for the last operation in autumn, as it effectively exposes the soil to the action of the atmosphere.

While describing modern improved agricultural machinery, we must not do injustice to an inventor who certainly was one of the pioneers in introducing one branch of such inventions. We here allude to Mr. McCormick, who invented, many years ago, a form of reaping machine, a description of which we quote from an account written by a personal friend.

After referring to the length of time during which the sickle has been used, he remarks:—"In America the 'cradle' superseded the old method before the close of the last century, which was a vast stride in harvesting. It was a scythe about five feet long, fastened to a framework consisting of six or eight fingers, or small rods, extending parallel with the scythe. Suspended by a strap from the shoulder, this apparatus was easily worked; and an expert hand could cut about two acres of wheat per day. It cut a swath about five feet wide; and the wheat was beautifully and evenly laid, ready to be raked in piles or heaps for the 'binder.' In the agricultural districts, it behoves the farmers to engage their labourers long ere the corn ripens to its golden hue; and, as the demand for them is generally greater than at any other season of the year, they command a correspondingly higher scale of wages. The scarcity of labourers often occasions a loss to the farmer, as the delay in gathering the corn after it has fully ripened, in some instances, has inflicted upon the proprietor the loss of the crop by heavy storms and cereal diseases. The 'cradle' lessened the expense of gathering the grain; but even in its employment the delays in harvesting were found to be dangerous. This led the ingenious mind to contrive means to economise, with respect to time and labour, in the gathering of the ripened corn, whether wheat, rye, oats, barley, or buckwheat; and this great achievement was accomplished by Mr. Cyrus McCormick, of the valley of Virginia, in the production of his world-renowned 'reaping machine.' For much more than a quarter of a century, the McCormick agricultural implements have been common to every farm in Virginia; and as the people of that State spread, from time to time, throughout the West, they carried with them the improvements invented by their fellow-countryman. The widespread prairies, and vast cleared woodlands of the great West, having become the wheat-producing region of America, McCormick, about twenty years ago, located his manufactory at Chicago, where he has produced thousands of his reaping machines. Indeed, it has been stated that, in 1867, his income from such sources was little short of £40,000 annually—a high testimony to the successful ingenuity of the inventor.

"The instrument is very simple in its construction, and is capable of cutting about fifteen acres of wheat daily. At the same time, it delivers the straw, &c., in heaps ready to be bound in sheaves of convenient size for stacking. Two horses walking in the swath last previously cut, draw the machine, which is fixed on wheels; and revolution of these wheels puts in motion a gearing apparatus, which produces an undulating, or 'to-and-fro' motion of a saw or teeth-cutting nature, by which the crop is cut. After thus being cut, the straw and head fall upon a plank-floor bed, which is pushed continuously into the earth by a kind of rake that acts at the same time with the wheels of the carriage or machine, from which the whole motive-power of the arrangement is derived. The invention of the rake has greatly enhanced the value of the 'reaper,' because it saves the expense of a labourer to do that particular kind of work. It is easy to calculate the economy resulting from the use of McCormick's reaper, compared with what is ordinarily performed by the sickle. By the 'reaper,' one man and two horses can cut fifteen acres of heavy corn per day; but by the sickle, in the hands of one man, only about half an acre can be cut daily; and besides this, the straw is cut close to the earth, leaving a very short 'stubble.'"

The preceding quotation shows how much machinery has done for the farmer by the invention of McCormick. We have already described in this chapter the most recent and improved forms of reapers and mowers as now in general use. Formerly, reaping required many hands to accomplish it in proper time, so that the corn which is ready for the sickle may not be too ripe and shed, nor the fair weather be allowed to pass before all the corn is secured in barns or stacks. The labourers who are required all the year for the common purposes of husbandry, seldom suffice for the harvest, especially on extensive farms; and recourse is usually had to the assistance of mechanics and artisans from the neighbouring towns and villages where the population is considerable, or labourers are induced by good wages to come from a distance. Soldiers in neighbouring barracks are often employed. As the harvest is later in those parts of every country which have a more northern situation, or are higher above the level of the sea, bands of reapers from these come to assist in the harvest of those tracts whose produce is earlier.

The hand cutting of the corn is effected by the *reaping-hook* or *sickle*, one of the most ancient of all implements. In reaping with the sickle, a portion of the stems is collected with the left hand and held fast; while the sickle in the right hand is inserted below the left, taking the stems in its semicircular blade, and cutting them through by drawing the sickle so as to act as a saw, for which purpose the edge is finely serrated in a direction from the point to the handle. The heads of the corn, with the upper parts of the straw, are then laid on the ground in quantities which may readily be collected into a sheaf. The division of labour is introduced with advantage amongst a band of reapers. A certain number cut the corn, while others follow to gather the sheaves; some only preparing the

bands, and others tying them, and setting up the sheaves into stooks or shocks, which usually consist of ten or twelve sheaves.

*The Management of Steam Power on the Farm.** —We shall conclude our remarks on the mechanical operations of the farm by some general directions, that may be of considerable practical value to any of our readers who may be desirous of using steam in place of human or other labour on the farm, excepting water-power, which is rarely available.

Steam-power is certainly the cheapest form in which a help to labour can be obtained; because, although the water-wheel and windmill may be, at first cost, lower in expense, still they cannot be depended on. At times they are in the most active operation, and require the greatest care in their management; and, at other times, either the stream becomes so sluggish, or the wind so calm, that both the wheel and the sails of the mill become stationary. When, however, either of these, by accident or local circumstances, are available, many of the ensuing remarks will be equally applicable in respect to the management of steam machinery.

In the first place, and as a general rule, nothing is more essential for the good working of all kinds of machinery, than that the shafts, cog-wheels, and every other moving part, should *be kept scrupulously clean from dust and dirt, and well oiled.* We have seen a forty-horse power engine, in a manufactory, dead-locked through neglect of such matters, when one of twenty-horse power would have been amply sufficient if every bearing, shaft, wheel, &c., had been kept clean, and properly oiled. Some years ago we were standing by a spinning-frame that required about two-horse steam-power to work it; but owing to want of oiling, upwards of five-horse power was insufficient to move it; and the extra power, after tearing off several teeth from the cog-wheels, at last bent a steel frame an inch thick, three inches wide, and forty feet long, so as to make it useless.

Now, if the agriculturist neglect the precaution of keeping his own or hired machinery clean, and properly oiled, he not only runs the risk of damaging the machinery, and paying for a longer period for its hire, but also incurs the extra expense of fuel for obtaining sufficient power for his purpose, whatever that may be.

For example, we may suppose him to be threshing by steam. Carelessly he allows the sand, dust, &c., from the straw, to settle on the cog-wheels of the engine. The consequence is that every deposit of the kind not only increases the friction of each part, but wears them out; and if the machine be his own, he incurs the almost inevitable result of wearing it out in much less time than if every part was kept constantly clean by wiping it with cotton, or other waste, and occasional oiling.

When a farmer keeps his own portable engine for driving any form of machinery on his farm, it is naturally to be expected that he will take proper care of it. But, accustomed as we have been to the management of "manufacturing" and farming steam machinery, we cannot but notice the wonderful difference that is to be seen between the attention paid to each. If we visit a first-class manufactory, we find the engine and engine-room a pattern of cleanliness and neatness. The floor of the engine-room is whitened, and, in many cases, carpeted! Every part of the engine, except such as are enclosed to prevent the radiation of heat, is brilliantly polished in dry weather; but, in wet weather, is covered with a coat of tallow. In fact, the individual who attends an engine, often takes more care of, and pride over it, than he does of his wife and children. The consequence is, that the slightest scratch, cause of friction, or other circumstance likely to impair its efficient working, is guarded against as carefully as possible; and, in a word, nothing that experience can suggest is left undone to promote the thorough efficiency of the engine.

Next, turning to the farm, we notice a much more elaborate and "risky" piece of workmanship exposed, without cover, to rain, wind, storm, &c.; and, at night, put into a shed not fit certainly to hold cattle. In the day-time it is dragged forth to its work amongst the dust of the fields; and all day long it is exposed to that and the dust it creates itself. Altogether it is open to every possible chance of injury, independent of the utmost care that may be devoted to it, rendering the latter of still higher importance than even is required in the case of the stationary engine, which is never exposed to the chances, dangers, or injuries to which we now allude.

It is therefore especially incumbent on the farmer to keep his portable engine free from dust, and well oiled; because, as we have shown, his steam-engine, whether portable or stationary, is liable to many more risks than the steam-engine of the factory. At least, and independent of the regular cleaning, &c., by day, the engine, if portable, on the return to the farm-shed at night, should have every bearing, shaft, and cog-wheel carefully wiped clean by cotton-spun waste or rags; all oil, &c., acquired by day being carefully rubbed off; because the longer it is left on the surface, the harder the oil becomes, and the more difficult is its removal; for, by the action of the oxygen of the air, it becomes oxidised and hardened, and *converted into a kind of varnish.* The bearings, &c., should not be again oiled till shortly before taking the machine out again to the field, or bringing it into use at the homestead; because, as just stated, exposure to the air speedily hardens the oil.

The best oil, next to sperm, or, perhaps, even superior to it, is paraffin; indeed, we much prefer the latter, because it cannot possibly harden in the atmosphere. All parts that are naturally hot during the working of the engine—as, for example, the piston, its rod, &c.—are better "oiled," or lubricated by good melted tallow; sheep's fat, well rendered down to remove the skin, &c., being by far the best for the purpose.

A properly-arranged engine has grease-cocks,

* Remarks have already been made on this subject at a previous page.

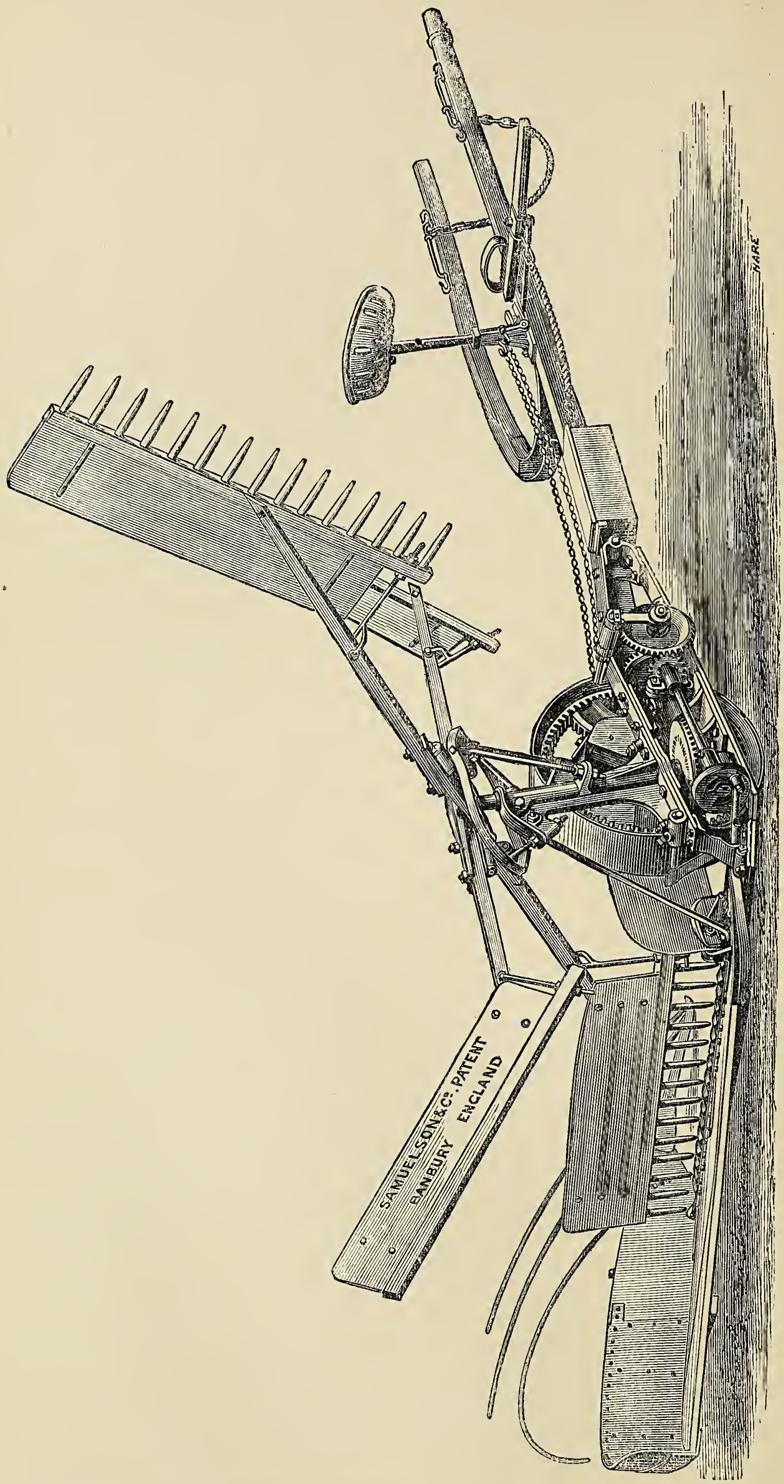


Fig. 326.—Patent "Original" Self-raking Reaping Machine.

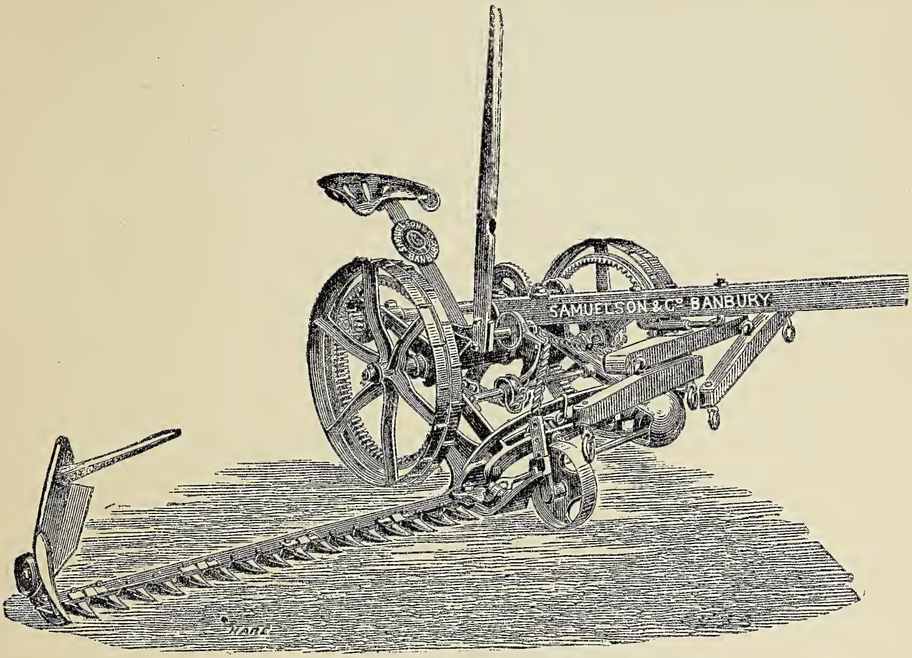


Fig. 327.—"Gem" Balance-draught Grass Mower.

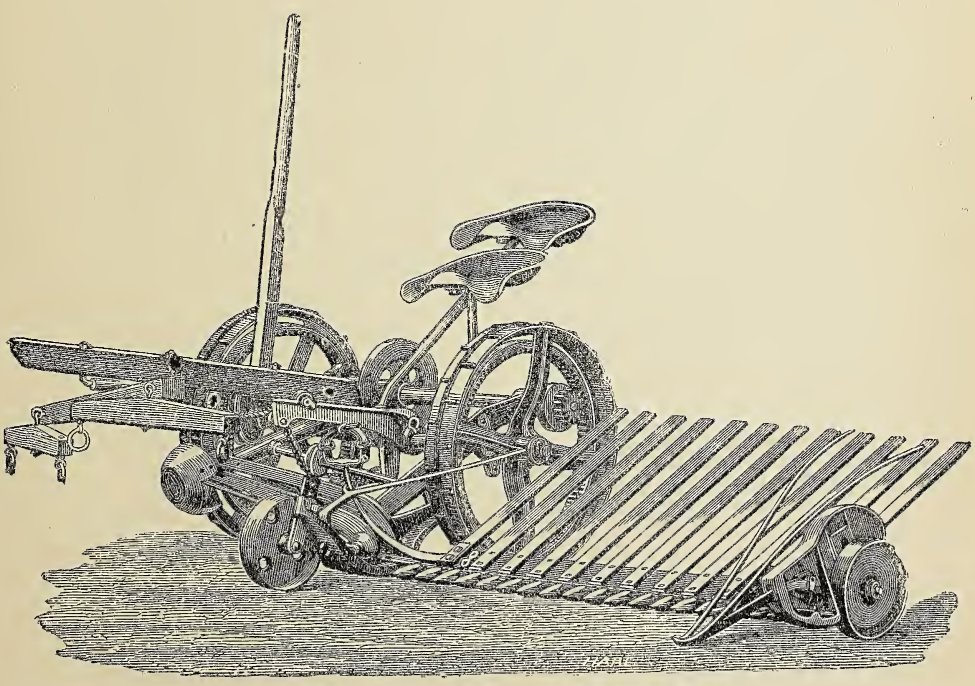


Fig. 328.—Balance-draught Combined Mower and Reaper.

by which tallow may be let into the cylinder without the escape of steam, or danger of blowing out the melted matter on to the face or the hands of the attendant. One great cause of injury to the cylinder, and loss of fuel, in most agricultural steam-engines, is that of placing the cylinder horizontally; because, in course of time, the piston wears down the lower part of the horizontal cylinder into an oval form, by which the steam escapes into each end. But careful oiling and cleanliness will prevent this to a large extent, and thus save the expense of re-boring the cylinder, that would otherwise be sooner necessary if these precautions were neglected.

Many fatal accidents have occurred from explosions of the boiler of portable engines, lent to, or possessed by, the farmer; but they are all traceable to causes that can, with ease, be prevented. For example, but a month before these lines were penned, a man was foolish enough to *tie down the safety-valve* by means of a rope—a plan about as dangerously fatal as placing a thick pitch-plaster over the nose and mouth of a man, or any other animal that breathes. The safety-valve of a steam-boiler is that which allows of the escape of steam when at such a pressure as to become dangerous. That is its object and office; and to overweight such a valve, or otherwise to obstruct its free action, is little short of determining on the commission of murder; for it is impossible to tell what result, in extent or character, may take place in regard to the destruction of life and property.

Occasionally, the safety-valve of a steam-boiler will stick. Numerous causes tend to produce this, but especially corrosion: any danger in this respect, however, may be obviated by instructing the person attending to the engine, to occasionally lift the safety-valve, so as to see that it is in proper action or condition. The gauge for indicating the pressure requires also constant attention. It acts as a check on the safety-valve; so that, if the latter be out of order, its indications should at once point out that fact.

Next to danger of explosion arising from too great a pressure of steam, and frequently causing it, is permitting the boiler to get too low of water. This, of all causes, is that most frequent in producing boiler explosions, for the following reasons:—

When the internal surface of a boiler, that should be covered with water, is left uncovered, it soon gets very highly heated; because the water which would rapidly take off that heat, and be converted into steam, is absent. At last, such a portion of the boiler gets red-hot. The engine-driver, meanwhile, increases its supply, and, gradually, the red-hot plate becomes again covered. But although so much water has been pumped in, the supply of steam does not at once increase; on the contrary, it may, and most probably will, *decrease;* because the cold water added will lower the temperature of that already in the boiler. But the red-hot iron plate, although in contact with the water, will not touch it until its temperature is lower. Thus, if a few drops of water be put on to a piece of red-hot iron, they will not be converted into steam, but will run off as water from the surface. As the iron cools, however, the water, if again dropped on, will, at last, suddenly be turned into steam. Now, precisely the same thing will happen in a boiler that, allowed to get short of water, has had some of its plates made red-hot. On the addition of fresh cold water, *the pressure of the steam will fall;* but, all of a sudden, it will rise, and, in nine cases out of ten, the boiler will burst. It is hence of the utmost importance to keep up a regular supply of water, the height of which in the boiler should be constantly and carefully watched.

If there be the least reason to suppose that any plate has got red-hot, *at once increase the fire*, and, as speedily as possible, *empty the boiler of water.* Instantly after rake out all the fire, and *leave the boiler to cool down before it is again filled.* This is the only plan of preventing a dangerous explosion, and injury to the boiler itself; and to ensure these results, the instructions just given must be attended to instantly and implicitly.

Another cause of injury to boilers, and to the cylinder by priming, is the use of hard water, and not blowing out the boiler constantly to remove mud, or the deposit from the water, which, when present in any quantity, produces what is called fur—a chief cause of many boilers, of all kinds, wearing out rapidly. This is familiarly seen in an old used tea-kettle, which, although clean and metal-polished at first, becomes gradually coated with earthy substances, deposited by the water that previously held them in solution, and to which we have already alluded at p. 357, *ante*, when speaking of lime as a cause of hardness in water. If the boiler is supplied from a well, this deposit will generally occur with rapidity, because of the quantity of earthy matter that well-water usually contains; as does that of most springs. River, but especially rain-water, is therefore best to supply the boiler with; and next to these pond-water should be chosen.

If, however, hard water must be used, or if any water used causes a muddy sediment, then every hour a small portion of the water of the boiler should be blown out, if possible, from the bottom. As long as the fire is beneath the boiler not much danger exists of furring; but when the fire is put out, the fur settles, and soon becomes a thick coat, harder than stone. We entreat our readers not to believe nor trust in any means of removal but that of constantly blowing off, and changing the whole water of the boiler as often as possible. We have tried, and seen tried, scores of methods of a chemical nature, all of which not only do, and *must* necessarily, fail, but have the additional evil of injuring the boiler, the slide-valve facings, the safety-valve seat, &c., &c. On board government steamers, and with every well-regulated boiler, "blowing off" the water of the boiler is alone resorted to.

We spoke of "priming," by which is meant the passage of water and mud from the boiler to the cylinder; and that arises from the condition of the water just described. Other causes also exist. Thus, suppose a steam-vessel passes from fresh to salt water in going down a river, on entering the salt water the boilers generally prime; but this cause, of course, does not affect the farmer, with whom the chief reason of priming will be the foulness of the water of the boiler, or of the latter being too full of water.

The supply-pump requires occasional examination, as small pieces of coal, straw, &c., are apt to get between the clack, or valve, and its seat. This is a common cause of a deficient supply of water to a boiler, and, consequently, an equally common cause of explosion from want of water.

The packing of both the pump that supplies the water to the boiler and that of the piston of the cylinder (if not metallic, which is now universally the case), must be carefully looked to. If even, as should be, the piston of the steam-cylinder is metallic, still the springs may get out of order, and, consequently, a loss of steam, as regards the main cylinder, would at once occur. It must be remembered that, as a farm engine makes far more strokes a minute than any other form of a steam-engine but the railway locomotive, the sources of loss of steam are great, and, what is still worse, incessant. Hence the economic use of steam on the farm essentially depends on careful attention to matters now under review.

The longer a steam-boiler is used the greater is the amount of fur deposited in every part; hence attention to the cocks or taps of the water-gauge is highly requisite. Even in the common kitchen boiler, the tap, by which water is drawn off, often becomes entirely closed from the deposition of earthy matter of the water introduced into the boiler. Consequently, the cock attached to the water-gauge requires careful examination at short intervals.

In starting a portable or stationary engine, care should be taken to first drive out all water from each end of the cylinder. Nothing in nature is more incompressible than water; and, for want of the precaution to which we now allude, we have seen the bottom of a cylinder, eighty inches in diameter, blown out from the nuts and screws holding it. Hence the common practice of locomotive engine-drivers, when they first start from a station, of letting off the water with the steam at each end of the cylinder. This drives out the condensed steam or water, and so prevents any possible injury to any part of its machinery. In buying a portable or other form of steam-engine, care should be taken that both top and bottom of the steam-cylinder is provided with what is technically known as "blow-off" cocks.

Of course, in purchasing a portable or other steam-engine, the farmer must be guided by the requirements of his circumstances. But the mere question of "horse-power" is of the most fallacious kind. Thus, if a man buys an engine supposed to afford four-horse power at a pressure of steam equal to 30 lbs. per square inch, by doubling that pressure the same sized cylinder will afford him *at least* double that power, if he use steam at a pressure of 60 lbs. per square inch, in respect to the indication of his safety-valve and gauge.

But, of course, the boiler must do double work; or, in other words, it must sustain a double pressure for that double work. From experience, we recommend that no one should use a boiler the plates of which are less than three-eighths of an inch thick, at a pressure higher than 40 lbs. per square inch, *the boiler being new*. We have worked such a boiler, *new and clean*, up to a pressure of 80 lbs. per square inch, the boiler being three feet in diameter; but it was not a wise proceeding. Yet we plead long practical and scientific knowledge for running such a risk; and, still more, a momentary supervision of every condition that might possibly lead to an accident. We have even risked 120 lbs. per square inch on a $\frac{3}{8}$th to $\frac{5}{16}$th boiler-plate; but, in the same case, ran the simple risk of what is the recognised allowance of pressure under all usual conditions of safety.

We mention these matters purely for the purpose of warning those unused to the management of steam machinery. Such persons will be told—"Of course you may use a high pressure, because it has been done before"—but only by persons capable of judging of the risk they run. For example, two of the most eminent engineers of this century made a bet that they would run a locomotive, for a distance of 112 miles, at the rate of sixty miles per hour, on certainly the safest line in the kingdom. They did it, and neither was injured; but they took the precaution of making their wills beforehand. They then took all the care that common sense and science could suggest; and we only relate this anecdote to warn all who would endeavour to get more work out of an engine than it is guaranteed to perform, to be exceedingly cautious as to what they do.

In the marine and commercial steam shipping, it is usually supposed that the nominal horse-power of a steam-engine is not certainly so much as a third, and, very commonly, only one-sixth of that which the engine can perform. But in such instances, refinements of science, both in construction and daily work, are introduced, which the agricultural steam-engine is perfectly incapable of. For example, expansion gearing, and consequent high pressure, with condensation of steam, anteceded by the super-heating of steam, are all accessories to an economic use of steam as a motive-power. But all these are far beyond the "ken" of the farmer; and it is therefore useless for us to enter here on their consideration.

Much economy of working a portable engine, in respect to farm and other operations, is derived from what has been called, "wire-drawing" steam. For example, at first starting any machinery, all the friction of each bearing, and every other part, has to be overcome. Yet,

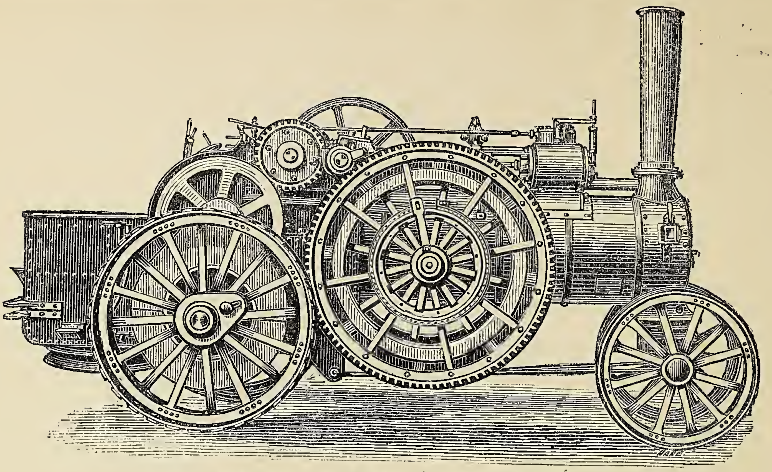


Fig. 329.—Patent Universal Engine.

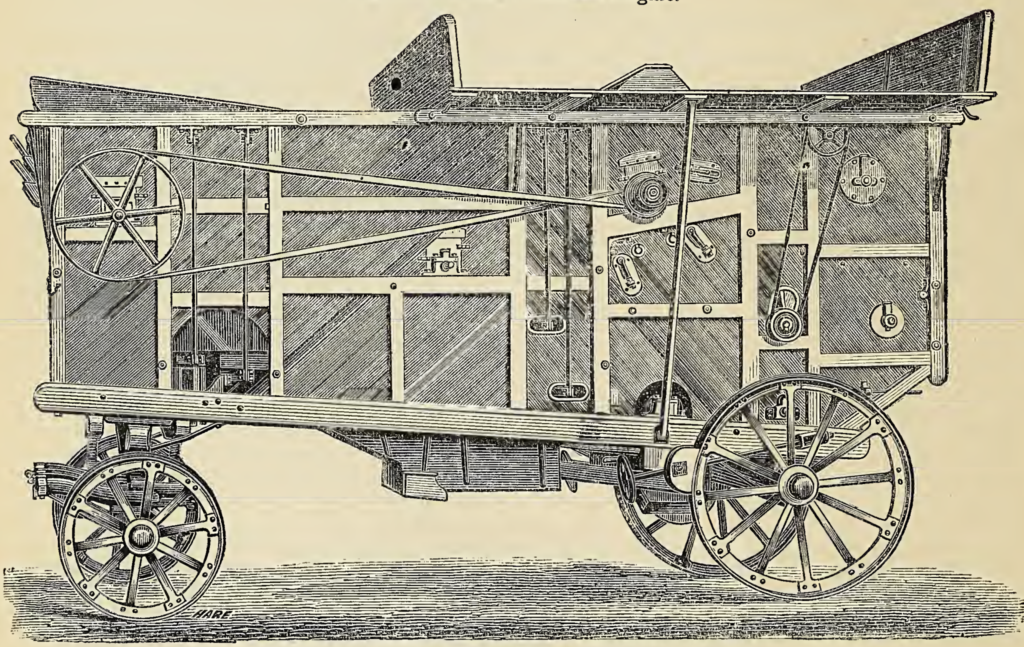


Fig. 330.—Combined Threshing and Finishing Engine.

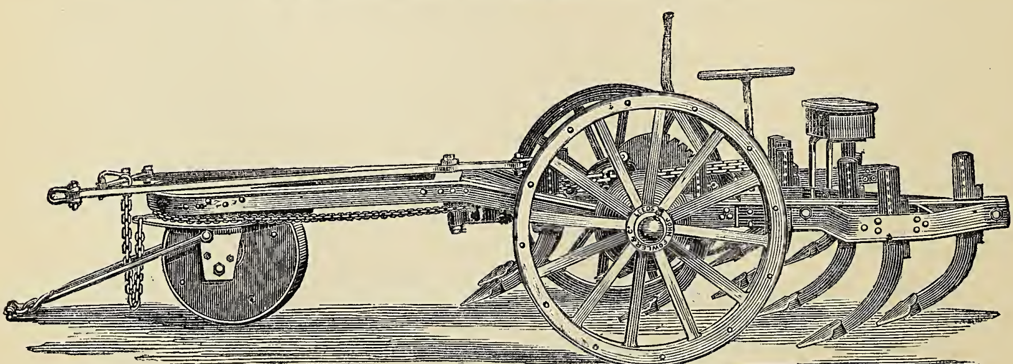


Fig. 331.—Combined Turning Cultivator.

when once the whole machinery is in operation, but little power is required to keep it in motion. When a locomotive engine-driver starts from a station, he has the whole of the weight of the train to put into motion: but when that is effected, the engine has but little to do. Just so in all operations wherein steam is employed. So soon as the *inertia*, or what we may call the "want of motion," is overcome, then the sustenance of that motion requires but little power. Hence the farmer, by carefully attending to this fact, may greatly economise fuel. The railway companies have long taken advantage of this, and a considerable portion of the wages of a driver of a locomotive is derived from savings of coke and coal thus effected.

Wire-drawing chiefly consists in so closing the cock, or valve, that intercepts the passage of the steam from the boiler to the cylinder, that only a narrow stream of steam, of high pressure, passes; but when the steam enters the cylinder, it expands, and does, without expansion gearing, a large amount of work economically. It is impossible, on paper, to give exact directions for so managing steam, because at every moment a greater or less amount of power may be required for any special amount of work. The farmer will do well, to ensure such economy as we refer to, first to get a guarantee from the person of whom he purchases his engine, that it will perform a certain amount of work by the consumption of a definite amount of coke or coal. Having obtained this information, it lays in his hands to offer such a premium on a lesser amount of fuel used, to his engine tenter or driver, as may result in benefit to both master and man. A little experience will guide him in obtaining the best results in both circumstances.

Frequently, in communicating the power of an engine, by means of a strap, to other machinery, much force is lost, owing to the "slip" of the strap. A little powdered rosin spread over the inside of the strap—that is, that part which laps on the wheel—will add so much adhesive power as to wonderfully remedy the apparent loss occasioned by want of adhesion. It is also desirable, except in the use of *gutta-percha* as a material for straps, that leather straps or bands should be kept well oiled. This preserves them from the attacks of insects, and, at the same time, maintains the adhesive power on the driving pulley.

And here we may note that the width of a driving pulley is a matter of much importance; because the wider, within certain limits, that is, the greater facility is afforded to the communication of power. Until very recently, the mechanical properties, qualities, character, conditions, or whatever we may call them, of motive-power, have been but imperfectly understood. For example, in former days, the ports or openings by which steam is admitted by the slide-valve of the steam-engine, were made, according to rule, very narrow; now they are largely increased in total area, and the result is, that the same quantity of steam travels far faster to the cylinder from the boiler, and performs its work far more efficiently. In our younger days we remember that a very narrow and slack band did the work of its much broader and tighter successor. The farmer, and all others using steam-power, should bear in mind, that every extra stroke of a steam-piston in the cylinder, with the use of the same amount of fuel for a less number of strokes, adds to his profits. It is within our personal experience, that one extra stroke of the engine, in a certain factory, made a difference of £2,000 annually to a manufacturing firm; and although we now write for those who cannot expect to make such an enormous difference, in any possible case, on the farm as regards their annual income or returns, still the principle holds equally good in both cases. "He that despiseth littles &c.," is a maxim of the utmost importance to all persons using artificial motive-power.

There are numerous other details in the management of a stationary or portable steam-engine worthy of remark; as, for example, careful attention in starting the engine, allowing only a small amount of steam first to enter; blowing out the water in the cylinder, as already alluded to; attending to the governor, by which the amount of steam introduced into the cylinder, and, consequently, the power exerted, is regulated; taking care that its strap does not become loose; having a cover for the top of the funnel for the escape of steam and smoke, lest sparks or cinders should pass, and set fire to the stack or barn; regulation of draught, &c. But most of these minor points of practice will be gradually learned, and an intelligent person cannot fail to perceive them, nor to under-estimate their value.

In respect to *firing*, a few words of advice may be offered. It is a great, common, and stupid fault to put a vast deal more fuel on the fire of the furnace, whether of a portable or stationary engine, than it can consume. It is generally supposed that the more coal, or other fuel, that can be placed on a fire, the greater the amount of steam produced—an error as ridiculous as it is wasteful. Many years ago, having some interest in a company of steam-boats on the Thames, in which it was of essential importance that speed should be attained, and having obtained full permission to do as we chose, we urged the necessity of thin firing as the best mode of attaining the object sought after. A race between two steam-boats, of nearly equal horse-power, was arranged for between Gravesend and Blackwall, on the Thames, simply to decide the question. We undertook the superintendence of six furnaces of one of the boats on the occasion; and, starting with clear fires—that is, free from clinkers—succeeded in beating a boat generally considered faster in that distance, and, at the same time, saved a quarter of a ton for every ton previously used. Applying the same principle, in subsequent years, to three twenty-horse egg-end cylindrical boilers, precisely the same result was attained.

Now, a few tons of coal apparently lost in a year does not seem much; but a principle is involved in such an economy. Would a farmer,

for example, like to lose annually twenty-five out of every hundred sheep, oxen, cows, horses, goats, pigs, corn, hay, grass, turnips, carrots, mangold, &c., &c.? Of course not. Hence a principle of wise economy introduced into one branch of his farm, at the same time introduces the same into every branch; and, therefore, raises not only the total amount of annual net production, but induces a judicious and salutary system throughout the whole concern.

Much injury is frequently done to a portable steam-engine for farm uses, by careless removal. It should be borne in mind that, whilst every part of an ox, cow, horse, or other domestic animal, is elastic in its texture, and is capable of withstanding all the jolts of either a town or country road, a portable steam-engine cannot stand, without some injury, such treatment. Every jolt affects, first the springs, and next the connections and bolts. Hence a hired engine runs great risk of injury in all parts In fixing a stationary engine, the engineer exercises the greatest possible care to prevent every chance of vibration.

We need scarcely state, that a locomotive engine, travelling even at a moderate speed, undergoes much jolting; but great care is taken to give all its parts such a "spring" as, most probably, would prevent any chance of injury. Yet the locomotive moves on a rail made as level as practical science can suggest. The farm portable steam-engine, on the contrary, has to undergo a much more severe treatment, under the best of circumstances. Drawn by a horse, whose motion is irregular, it has to surmount all the rough materials of the road, such as stones, ruts, hollows, and many other obstacles to its progress. Hence it is impossible to take too much care of a machine apparently very strong, yet, practically speaking, requiring as much care as a watch.

For many years past the British farmer has had much to contend with. Adverse seasons he must, of course, expect, for, throughout the world, meteorological influences in the shape of excessive rainfall, and consequent floods, have always, on all kinds of crops, a serious influence. But still an average between good and bad generally occurs. Metaphorically, if we have our years of famine, so have we those of plenty.

At the present time, our islands are quite incapable of producing sufficient food for their population. We import enormous quantities of all cereal crops from abroad. Now, also, an immense quantity of live stock is imported not only from the continent, but also from northern America. Dead meat is imported also to an enormous extent, and the recent increase in the imports of preserved meats shows that our country is really dependent on foreign, rather than on home supply.

All these facts show that the British farmer is subject to severe competition. But precisely the same occurs in regard to our metal, textile, and other manufactures. But those engaged in the latter branches of industry have learned how to meet that competition successfully, and even to amass large fortunes by it. This result is simply arrived at by the way in which manufacturers carry on their business. They judiciously employ large capital, they adopt the newest and best inventions of machinery in each department, they save all possible of their raw material, and if they do make "waste," they try to turn it to account by some new process of manufacture.

It is only by following a similar course that our farmers can expect to meet the effects of foreign competition. In the previous pages we have endeavoured to show what may and can be done by him, if he will avail himself of means easily within his reach. He must follow the example of the manufacturer, economise all expenses, lay in a good stock in anticipation of a bad season, and thus exercise that most valuable, but rare of all the senses—"common sense."

CHAPTER XII.

GRAIN, GRASS, POD, ROOT, AND OTHER CROPS.

IN the preceding pages we have at great length noticed the various chemical, geological, physical, and other conditions that affect agriculture; the use and choice of manures, the analysis of soils, &c., have also been dealt with, and descriptions and illustrations have been given of some of the best modern appliances now used on the farm by aid of steam to economise labour, and otherwise to aid the agriculturist. We next turn to describe the chief crops produced by the farmer, including grain, grass, peas and beans, potatoes, turnips, &c.

As we proceed in the description of the various crops that the farmer has to produce, the application of what has been stated in the previous pages, and briefly referred to above, will become apparent, and so we may regard the future pages of this section as showing the practical application of the facts, principles, and laws that have been already enunciated, and the necessity which is incumbent on the agriculturist to put them into thorough scientific and practical use. By so doing he may, as a rule, have strong hopes of success, for although he cannot control the powers of nature, he has at least a chance of turning them more or less to his purpose.

It is a remarkable fact that the most common of all our "orders" of plants is that from which both man and the domestic animals derive their chief supply of food. To the grasses, or *Gramineæ*, as the order or family is termed by botanists, we have recourse for grass, hay, wheat, rye, barley, oats, rice, maize or Indian corn, millet, gero, the sugar-cane, and many other varieties of the family that minister to the wants of many animals. It is equally remarkable that all portions of the known world are productive of some form of the grass tribe, from Tierra del Fuego to Iceland; and from the shores of Ireland, eastward, as we progress through Asia to California, in the east or west, according as the longitude may be reckoned.

That there is great design evidenced in such an abundant provision for man and animals must be very palpable to the most cursory thinker. It cannot be an accident that the bleak fields of the north of Europe, the broad prairies of the northern portion of America, the plains of Southern Europe, of Central Asia, America, and even arid Africa, should all possess some kind of grass on which man and beast can live, and find all necessary sources of nutriment. Still more wonderful is it that, in all these and other climates, chemical analyses and botanical science discover an identity of constitution that otherwise (apart from what science always recognises as a rule) would indeed be marvellous.

But, as we have already noticed, there is a limit to the growth of all grass crops. In the south of Europe wheat cannot be profitably produced. Beyond a latitude of say 55° or 57° north or south of the equator, the varying temperature and climate render the cultivation of wheat and most cereal crops unprofitable, unless certain hardy species or varieties are chosen. There is, therefore, a kind of "selection of species" (to use a common but highly theoretical mode of expression), through which any climate in the world "brings up" its own vegetable children.

In Great Britain the use of different kinds of cereal crops has been a matter of frequent change; for whilst, at the present day, wheat is the almost sole source of our bread-supply, we find that, in former times, it was by no means so universally in use.

"It is curious to remark," says an able writer, "the changes of custom in England relative to the kinds of corn used for bread. The Anglo-Saxons of St. Edmund, in the eighth century, ate barley bread because the income of the establishment would not admit of their feeding twice or thrice a day on wheaten bread.' Piers Plowman, a satirical writer of the time of Edward III., remarks that when the new corn began to be sold—

> "'Woulde no beggar eat bread that in it *beanes* were,
> But of coket and clemantyne, or else clene *wheate*.'

"In a valuation of Colchester, in 1296, almost every family was provided with a small store of barley and oats; usually about a quarter or two of each; scarcely any wheat being noticed in the inventory, and very little rye. About the beginning of the sixteenth century the suppression of the monasteries in England, and the discovery of gold and silver in America, had much effect on the kind and price of corn used by the lower classes; and a legend of Somersetshire states, that 'before the vriars went thence, a bushel of wheat was zold for vourteen pence, and vorty eggs a-penny.'" As regards the wheat, we can say nothing in respect to such a price; but we have purchased, in the north of Scotland, within the last ten years, a dozen *new-laid* eggs for 1½*d.*

"The taste of the people about that period [1500, *et seq.*] is indicated by the remarks of Harrison, that 'the bread throughout the land

is made of such graine as the soil yieldeth; nevertheless, the gentilitie commonlie provide themselves sufficientlie of wheate for their own tables; whilst their households and poore neighbours, in some shires, are inforced to content themselves with rie or barlie.' And of the agricultural labourers, he says—'As for wheaten bread, they eat it when they can reach the price of it; contenting themselves, in the meantime, with bread made of oates or barlie—a poor estate, God wot.'

"In the household-book of Sir Edward Coke, in 1596, there are repeated entries of 'rie-meall to make breade for the poore.' In the time of Charles I., barley bread was the usual diet of the humbler classes. Eden says, that about the year 1750, 'so small was the quantity of wheat used in the county of Cumberland, that it was only a rich family that used a peck of wheat in the course of the year, and that was at Christmas.' Several years ago, we remember having seen a hamper opened (*cir.* 1837), that contained two dark-looking loaves, much of the colour of ginger-bread, which were sent as a present from Penrith to the family, together with a "Christmas pie," an enormous agglomeration of turkey, goose, ham, poultry, &c., &c., verifying, to a still later date, the use of rye as bread in Cumberland. "The usual treat for a stranger was a thick oat-cake, called 'havers-bannock,' and butter. An old labourer remarks, that when he was a boy, he went to Carlisle market with his father, and, wishing to indulge himself with a penny loaf made of wheaten flour, he searched for it for some time, but could not procure a piece of wheaten bread of any shop in the town. The labourers of the southern and midland counties, in the latter part of the same century, began to rebel against the kind of bread given to them, which consisted of wheat, rye, and barley, in equal proportions."

On the continent, rye and barley, with buckwheat, are common articles of bread diet in temperate and northern climes. So far as our experience goes, we have never seen, in England or Scotland, any bread diet other than that made, nominally, of wheat, not even in the lowest class of the population; but, about fifty years ago, whilst one-half of our population in Great Britain (omitting, of course, Ireland) ate wheaten bread, about one-fourth ate oaten, an eighth barley, and lesser numbers consumed rye, peas, and beans, in various forms, as substitutes for bread.

According to botanical arrangement, and as already mentioned, all our cereal or corn crops are ranged in the order of *Gramineæ*, or the grasses. The genus of that order, including wheat, is called *Triticum*; and the two most important species of that genus, are *Triticum sativum* and *Triticum turgidum*. The former, *T. sativum*, is that most cultivated in Great Britain; but, by various methods, a great variety of the species has been produced. Generically, wheat may be divided into the *bearded* and *smooth*; but, in commerce, the distinctions of white and red are more common. Then, again, there are the names of "spring" and "winter" wheat; but, to a certain extent, such terms are fallacious, because, by successive sowing of each or either, the varieties become convertible.

Fig. 332.—Spring Wheat.

A series of cuts represent some of the typical forms of wheat as now grown in Great Britain. Thus, in Fig. 332, an ear and plant of spring wheat is represented. In Fig. 333, an ear and plant of winter wheat is illustrated. And Fig. 334 shows an excellent Egyptian variety of wheat-plant, with its ear. It is this variety of wheat that was referred to as the subject of experiment in transplanting, previously mentioned.

Fig. 333.—Winter Wheat.

Of course, the varieties of wheat indicate that certain causes of a definite character have produced them; and it is an essential point for the farmer to ascertain what variety his soil is most fitted to produce. In poor soils, white wheats gradually become of a darker colour, whilst red wheats become lighter in rich soils. In fact,

the varieties of wheat, as of every other plant, are really dependent on the chemical and phy-

Fig. 334.—Egyptian Wheat.

sical conditions of the soil; and hence, within certain limits, the farmer may not only have his choice of growth, but, by proper management, may even convert one kind into another. In horticulture, and gardening generally, this principle is so well understood and acted on, that an almost infinite variety of species-production lies within the range of possibility. Thus winter wheat, or spring wheat, may be converted by repeated sowing at seasons of the year different to the names applied to them; but if the seed which belongs to the variety be sown at the period which its name indicates, its time of ripening will be, as an average, constant.

The preparation of the soil for wheat is a matter of great importance. All grasses are generally so tall at their ultimate growth, as to have barely strength to sustain an upright position, when full-grown, if any amount of wind should blow; and hence in wheat crops, especially if heavy in the ear, and wetted with rain, "laying" is a common occurrence for a few weeks before harvest. Now wheat, like all other forms of animated existence, requires its support. In man, and all the superior animals classed under the term *Vertebrata*, their support is found in the internal skeleton. In the *Mollusca*, as the cockle, mussel, oyster, &c.; and also in the *Crustacea*, as the lobster, crab, shrimp, prawn, &c., this support is found external to the body. And precisely the same thing occurs in reference to plants. As already stated at p. 359, *ante*, silica is the back-bone or support of plants of the grass tribe; hence the importance of its being abundant in the soil. At the page just referred to, there is stated the amount of silica that many crops take from the soil.

But it is not simply the chemical condition of the soil that must be attended to in its preparation for wheat; the mechanical conditions are of almost equal importance. It is necessary that a firm bed should exist for the support of the lower part of the stem and root of the plant; hence the admirable provision of aluminous or clayey matter in all good wheat-growing soils. Whilst, on analysis, we find no trace of alumina in either straw or seed, still that substance is absolutely essential in affording a firm bed or matrix, in which the plant grows. Hence the advantage, in light soils, of allowing sheep to graze; for their feet make the soil compact, and therefore fitter for the growth of wheat crops. At times the roller is had recourse to; but, after all, we question whether, except in very wet weather, it affords any advantage superior to that resulting from the tread of sheep. The latter certainly have the additional advantage of manuring the land by their droppings.

We can hardly, bearing in mind the general objects of this work, enter into lengthened details of the various circumstances involved in the preparation of the soil and seed of wheat, or other crops of the cereal kind. A large proportion of the preceding pages has been devoted to the consideration of all the chemical, physical, mechanical, and other conditions requisite generally to ensure fertility; and we must, therefore, not further trench on our presumed or implied limits to go over the same ground again in similar details. We have already, in the preceding pages, spoken of the prudence of thin sowing, whether by broadcast, drilling, or dibbling. The general principle to guide the farmer in all such matters, is to afford the plant all possible nutriment, consistent with such a growth as shall ensure the greatest strength of straw.

It may be remarked, however, that certainly dibbling seems to ensure all the conditions that render a wheat crop most fruitful, not only as regards the amount of ear-produce, but in respect to the strength of straw—a condition we have just alluded to. About a month before harvest—say the middle of July—our climate is commonly visited by heavy winds and rains; and the better the ear crop, the worse chance does the entire crop stand of resisting the effects of the storm. "St. Swithin" has just set in whilst these pages are in course of composition; and although, for three or four weeks previously, the weather has been inclined to drought, nearly three inches of rain have fallen within as many days, and the wind has blown, during the same period, a perfect gale. Such weather commonly occurs every year; and hence any method of sowing which gives increased strength to the straw should be adopted. Dibbling, we have no hesitation in saying, is the best method of sowing for obtaining this result.

Of course, in reaping, it is an important point to have every plant as upright as possible, because otherwise much loss must be sustained. Hence, if any special method of sowing is of value in various respects already mentioned, it becomes still more so in regard to the getting-in of the crop safely, readily, and plentifully. The transplantation of wheat, and all other cereal plants, greatly ensures such a result; but we are quite aware that, practically, the farmer

cannot carry out such a method on the large scale, although small plots may be treated so for experimental purposes.

The selection of seed is matter of high importance. In the exhibitions of recent years, the specimens of English wheat most admired for size and general abundant produce were the *Talavera* variety, especially adapted to a sandy or gravelly soil; the *Chidham*, more suitable for a rich soil; the *White Turnip*, sown and grown principally in the southern counties of England; and the *Red Nursery*, especially fitted for chalky, marly, or limestone districts. The effects of artificial selection were strikingly shown in the great improvements, on the whole, of English wheats, some showing very large ears, procured by preserving for seed, from year to year, only the largest ears, and thus obtaining an increase in the number of ears, and also of their size. The best specimens of wheat shown at the various late Exhibitions were grown from varieties of *Triticum sativum;* Australia especially being noted for producing specimens that gave an amount of produce equal to 68 lbs. weight per bushel. The *Triticum durum*, from Spain, Italy, Greece, and Algiers, also averaged about 68 lbs.; and the *Triticum polonicum* was almost equally productive. The average weight of Australian wheat was about 65½ lbs. per bushel, giving a per-centage of 83·5 of flour, and 16·5 of bran.

The manures applied to soils for wheat crops must, of course, depend on the nature of the soil, and its deficiencies. Analyses of wheat ash, and the abstraction of mineral matters generally from the soil, have been already given at pp. 347, 359, 384, 385, 442; and at other pages directly or indirectly bearing on the question of soil, and the application of manures. Of course, in all cases chemical analysis of the soil should be the guide; but certain empirical methods have been in constant practice. Thus, as Mr. Robert Scott Burn observes, in his able work, *Outlines of Modern Farming*—"The following gives an outline of modern practice in the use of artificial manures for the wheat crop:—In *sandy soils*, if applied in autumn, 2 cwt. of rape-cake, broken or crushed to a powder, with 2 cwt. of superphosphate, per acre. For spring-sown wheat, 1 cwt. of nitrate of soda, 1 cwt. of Peruvian guano, 2 cwt. of common salt; or 2 cwt. of sulphate of ammonia, and 2 cwt. of salt. In *calcareous* [chalky or marly] *soils*, 2 cwt. of salt, 2 cwt. of nitrate of soda, for spring-sown wheat. In *clay soils*, where wheat after turnips is taken, and sown in autumn, no artificial manure is recommended; but a spring dressing may be applied of from 2 to 3 cwt. of Peruvian guano, with 2 cwt. of salt, per acre. Where the wheat is sown in spring, this should be applied in two portions—half at sowing, and half at a later period, when the plant is well up. In *light vegetable moulds*, a dressing of 2 cwt. of salt, and 3 cwt. of superphosphate, per acre, sown broadcast in March, will be beneficial. As, in these soils, an excess of vegetable matter is present, lime will be essential after draining is effected."

As wheat is the main bread-stuff for man, oats may be considered in a similar light in respect to domestic animals. The oat is classed, botanically, under the genus *Avena;* and, like wheat, belongs to the grass order, or *Gramineæ*. In the annexed cut, the common and bearded oats are represented; the latter

Fig. 335.—Oats.

being shown in the left-hand cut. There are numerous varieties, and also species. The oat of this country is chiefly the *Avena sativa*. The Tartarean oat, or *Avena orientalis*, differs from the common oat in having its seeds growing all on one side, presenting somewhat the appearance of a bird's wing-feather with one side stript off.

Generally oats form a much hardier crop than wheat; and hence they are largely cultivated in the northern portion of our islands. Both broadcast and drill-sowing are adopted; and generally, in respect to various soils, the remarks already made in respect to manures for wheat, are, more or less, applicable to oats.

Barley is a crop of great importance, not in our islands for food, but for malting. It belongs to the *Gramineæ*, or grass order, of the genus *Hordeum;* but there are numerous varieties cultivated, amounting to nearly thirty. Like wheat, it is chiefly divided into *winter* and *spring* barley; and also the kinds are distinguished as *two-rowed*, *four-rowed*, and *six-rowed;* the four-rowed variety being common in England.

The three following cuts represent, respectively—Fig. 336, an ear and plant of spring barley; Fig. 337, an ear and plant of winter barley; and Fig. 338, an ear and plant of two-rowed barley.

On the continent, and some of the northern counties of England, barley-bread is common; but generally, in our islands, barley is grown solely to supply the wants of the brewer and distiller.

For this purpose it is converted into malt, by

which the starch of the seed is gradually converted into grape-sugar. As already pointed

Fig. 336.—Spring Barley.

out, the starch in all grain is intended, by nature, to afford the first food of the plant, or rather its origin. The mode of germination and growth has been already explained at p. 374, *ante*, and illustrated by cuts. It will be there seen, that immediately on germination taking place, two "processes" are formed—one being the plumule, which, in malting, is called the

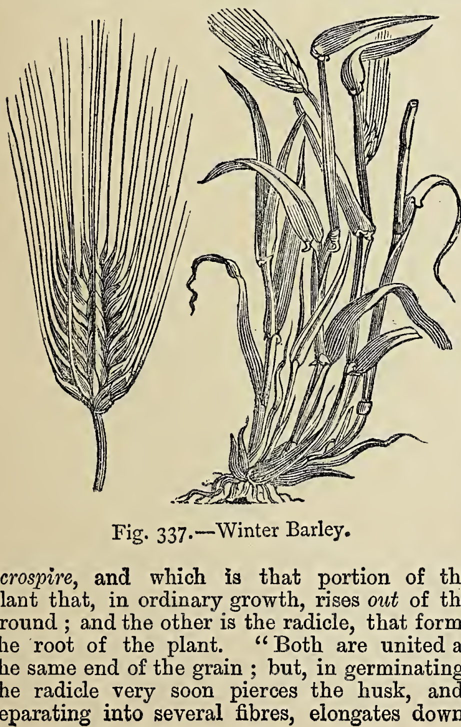


Fig. 337.—Winter Barley.

acrospire, and which is that portion of the plant that, in ordinary growth, rises *out* of the ground; and the other is the radicle, that forms the root of the plant. "Both are united at the same end of the grain; but, in germinating, the radicle very soon pierces the husk, and, separating into several fibres, elongates downwards; while the acrospire, but much more slowly, advances through the body of the grain,

Fig. 338.—Two-rowed Barley.

and piercing the opposite end, soon shoots up into a green blade [see Fig. 316, p. 374, *ante*], leaving the husk of the corn empty, and perfectly exhausted of its former contents. The radicle is much more rapid in its formation and growth than the acrospire; because, as it is destined to prepare and transmit to the stem all its food, it is necessary that it should be sufficiently matured to perform the office by the time the acrospire has consumed the store which provident nature had laid up for it in the grain. There is no difficulty in comprehending the first dawnings of vegetable life in the germination of barley. The grain, placed under favourable circumstances of moisture and warmth, imbibes both, and swells much; the radicle, lying the nearest to the exterior, is the most susceptible of these; it swells most and first under its new combination of moisture, and acquires an attraction for the oxygen of the atmosphere. The oxygen, as it becomes fixed, produces two powerful effects: it gives up that portion of its latent heat which it held in a gaseous state, and, by its fixation, enters into a new combination with the carbon of the starch, converting it into saccharine matter [grape-sugar, already described at p. 362, *ante*]. The stem part of the germ, previously swelled by the moisture, and now invigorated by the heat produced by the fixation of the oxygen, acquires an attraction for the newly-formed sugar, assimilates it to itself, and, in the chemical action of union which ensues, vegetable life is developed. Such simply is the natural process of germination in every species of seed, though here restricted to barley; and it is important to remark, that the heat arising from the fixation of the oxygen is the same which first becomes sensible in the couch, and afterwards continues to show itself, in different degrees, amongst the corn on the working floors of the malt-house. In the nice adjustment and

due regulation of this heat consists the most important part of the manipulations of malting.

"The formation of the sugar in the grain is slow and progressive, as the acrospire requires it; and hence it may easily be conceived that, between the first formation and final consumption, there must be a period of time when the largest proportion abounds in the grain; and this is the proper time for throwing the corn upon the kiln. * * * * Malting, then, is nothing more than the promotion of a healthy germination of the barley, up to that period when the largest proportion of sugar has been formed; nor can anything be more obvious than that, in a variety of modes to accomplish this, one must be superior to all the rest, and that not locally, but everywhere; because nature is everywhere the same. In every natural process, the varying of the means will necessarily produce a difference in the end; and in the two modes of malting—by watering the floor, or omitting to do so—there is so material a difference, not merely in the use or disuse of water, but in the time, management, and other circumstances, that the one cannot but be superior to the other in the quality of its respective commodity. A single instance cannot be produced of any natural process whatsoever, wherein nature permits the employment of two different means to afford precisely the same end."

Numerous precautions are, consequently, required to produce malt; and into the discussion of these we cannot here enter, as we have made the preceding quotation from Mr. Barlow, only to show the general principle on which the process of malting depends. In respect to the varieties of malt, they are usually divided into *brown*, *amber*, and *pale*. The colour is produced by submitting the malt to considerable heat; and the coloured kinds are chiefly used for porter-brewing, whilst the pale kind is fitter for ale, and the process of distillation.

As already noticed, it is for brewing and distilling that the growth of barley is carried on in this kingdom; and the amount required, of course, is very large. It is a hardy crop, and is usually sown in March and April; but may be sown advantageously in autumn in the southern portion of our island, where the rigours of winter are but slight. It is, perhaps, best sown by drilling; but, as with wheat, dibbling has its advantages, for similar reasons to those already expressed at p. 441, *ante*. By adopting dibbling, a good crop of both ear and straw may be secured under all average conditions of seasons. Nitrate of soda and common salt, in the proportion of one hundredweight of the former to two of salt, are excellent manures for a barley crop per acre. On clay lands, Peruvian guano may be used with advantage; and, generally, some or most varieties of phosphate manures will be found beneficial. But the choice of the manure must be guided by an analysis of the soil, for thus its requirements will be ascertained; whilst those of barley, and all other "grass" crops, have been already and repeatedly pointed out in the preceding pages.

Of *Rye*, little need be said: at one time with us, and now frequently on the continent, it has been a source of bread-stuff; but its cultivation in our islands is very trifling. In most respects, its treatment as a seed on the farm, whether in respect to soil, manures, or other conditions, resembles that of wheat; like which and barley, it is divided into spring and winter varieties. An ear and plant of rye is represented in the annexed cut.

Fig. 339.—Rye.

Rice, Indian corn, and Buck-wheat are never grown in this country, because the climate is unfit for the two former; and Buck-wheat, although of use on the continent, has never formed a bread-stuff in our islands. Rice and Maize, or Indian corn, both belong to the grass tribe; and in Asia and America are of the highest value. Indeed, in Hindostan, the East Indies generally, and many parts of Mid-Asia, rice is the staple food of the kingdom. It is grown in some parts of South Europe and Africa; but Asia and America are the chief countries where it is most largely grown and consumed.

Pasturage Grasses.—Although we have adopted chiefly grain crops for description under this heading, as ordinary grass belongs to precisely the same order as wheat, oats, barley, rye, &c., yet we may include with the preceding some notice of the best kinds of grasses for the agriculturist and horticulturist.

At the present day much variety of opinion exists as to the best kind of grass generally suitable for pasturage; and, after what has been said in the previous pages, the most unscientific of our readers will not hesitate to say that a certain principle of selection obtains, as a rule, in respect to different sorts. For example, at p. 410, *ante*, we have noticed that the application of sewage has the effect of driving away all leguminous plants, and of conserving those of a graminaceous or grass nature. Now, here we notice that the principle of selection is as evident as the taste of humanity is evinced for certain kinds of food, or mode of cooking it. Fully believing this principle, and always adopt-

ing it in reducing the principle to practice, we suggest the following selection of grasses, some of which have been already named, and the whole of which have the sanction of choice of one of the first agricultural seedsmen of our time.

Grass Seeds.

Cock's-foot	*Dactylis glomerata.*
Meadow Fescue . . .	*Festuca pratensis.*
Hard Fescue	,, *duriuscula.*
Narrow-leaved Fescue .	,, *tenuifolia.*
Fine-leaved Fescue . .	,, *heterophylla.*
Red Fescue	,, *rufra.*
Tall Fescue	,, *elatior.*
Sheep's Fescue . . .	,, *ovina.*
Crested Dog's-tail . .	*Cynosurus cristatus.*
Meadow Fox-tail . .	*Alopecurus.*
Tall Oat	*Avena elatior.*
Yellow Oat	*Avena flavescens.*
Yorkshire Fog . . .	*Holcus lanatus.*
Broad-leaved creeping bent	*Agrostis stolonifera latifolia.*
Sweet Vernal . . .	*Anthoxanthum, odoratum.*
Lucerne	*Medicago sativa.*
Smooth-stalked Meadow	*Poa pratensis.*
Long-stalked Meadow .	,, *trivialis.*
Wood Meadow . . .	,, *memoralis.*
Evergreen Meadow . .	,, *sempervirens.*
Timothy	*Phleum pratense.*
Yarrow	*Achillea millefolium.*
Italian Rye	*Lolium Italicum.*
Pacey's Rye	,, *perenne.*
Perennial Rye . . .	,, ,,
Annual Rye	,, *annua.*

Many, indeed most of the preceding are indigenous or native to many of the soils of this country; and, as such, give little or no trouble to the farmer in their cultivation. In some cases, however, certain of the species of grass mentioned in the preceding catalogue cannot be grown in soils on some farms. But the seedsman, in most cases, can fully advise the farmer on such questions, and chemical analysis will much aid in such a selection.

In regard to *clover*, many varieties are cultivated; as, for example, the Alsyke Hybrid, which, as a perennial, thrives in any soil. Italian clover, the *Trifolium incarnatum*, is one of our best for early crops. Besides these, we may name the Bokhara, or Giant, the flower of which is much prized by bees; the Perennial Red, or Cow Grass, which makes excellent permanent pastures; the Red, or Broad-leaved, which is biennial, and affords heavy crops; the Suckling, *Trifolium minus*, highly suitable for lawns; the White, or Dutch, which makes good pastures; and the Yellow, or Trefoil.

Tares are crops with Vetches, that must serve the farmer's purpose as food for the domestic animals. Although they belong to an entirely different class of plants to the grasses, we still here name them, because they are part of the green crop of use on the farm, and in the stable. Vetches belong to the order *Leguminosæ*, because their seeds are found in pods. They may be prudently grown between two grass crops; and as they are by no means confined to special soils, form an excellent "stolen crop" on almost any kind of land. The crop is sown both in autumn and spring; and towards the end of a warm May, or an average June, it becomes of great use as food for live-stock. It may be advantageously sown with rye, which, as in this country is not usually grown as a cereal, may be employed with the vetches as a green food.

Sainfoin and Lucerne are similar in character, the former being especially suitable for marly or chalky soils. Clover and sainfoin are often sown with a straw crop, instances of which are very common on the chalky soils of Kent. Lucerne, from the uncertainties of our climate, does not produce well, except in the south of England. Hence it cannot be depended on as a crop mixed with others, but should be sown alone.

In respect to rye-grass, so many remarks have been made in regard to it, and the application of sewage for its production, at p. 396, *ante;* and in the tabular statement at p. 419, *ante*, that we may at once dismiss it. Like clover, and many other kinds of grass, it accommodates itself to a great variety of soils. It generally succeeds, in rotation crops, a grain crop; but it must be remembered, that as a member of the *Gramineæ*, like all the cereals, its requirements are so similar to those of wheat, oats, barley, &c., that, chemically speaking, such a succession on the part of rye, has no warrant in a scientific point of view. By an abundant use of town sewage, an enormous crop may be obtained per acre; but of the value and use of this, we refer our readers to p. 396, *ante*, for data on which to arrive at correct conclusions.

In growing grasses, of course, the farmer carefully bears in mind to what purpose he intends to devote his land—whether as permanent pasture, or simply to raise a crop or two in succession, as a rotation crop, in respect to grain or other crops.

The amount of seed sown in the latter case varies; and a judicious selection of various grass seeds, such as have been named and catalogued in this page, together with clover, will form an excellent permanent pasturage; whilst in alternate cropping, Italian rye-grass, yellow hybrid, red perennial, and white clover, form, with cock's-foot grass, an eligible selection. But, as already named, the soil should determine the choice of the grass crop; and as our directions here can only be of a very general character, we must forbear entering into details on such a subject.

In respect to top-dressing of soils intended to produce grass, it may be observed, that as all cereal crops are connected so essentially, both botanically and chemically, with the grasses, the advice for the one is equally suitable for the other. Of course, whilst man feeds on the cereal, the ox and sheep tribe similarly depend for sustenance on grass proper. Guano, phosphates, nitrate of soda, soot, bone-dust, stable and farmyard manure generally, and other manures already mentioned, are all valuable or essential on pasturage lands.

In applying any or most of the manures named, regard should be had to the time of application. Those that require a long time to decompose, should be applied in October or November, to give stimulus to the spring crop; whilst the lighter kinds of manure may be employed in early spring. Sandy soils, for example, are benefited by the application, say of a hundredweight each of guano and nitrate of soda per acre, in March. Clay soils, about the same period, receive with advantage twice that quantity of guano, a hundredweight of sulphate of ammonia, or three hundredweight of soot, which, as already pointed out, is of value chiefly on account of the quantity of sulphate of ammonia that it contains. To chalk soils for grass, two hundredweight of each, guano and salt, per acre; a few hundredweights of soot; a hundredweight of nitrate of soda; a liberal quantity of rotted seaweed, or of sea-fish, are all of great advantage. In many parts of Kent, and the east coast generally of England, seaweed and sea-fish are largely used, both for cereal and grass crops.

In applying manures to grass lands, the principle of stimulating or permanently enriching must be borne in mind. If the farmer desire a speedy and luxuriant crop, of course he must use not only an early and rich-growing seed, but also such manure as will force its growth; and guano, with or without nitrate of soda, is of the greatest value for such purposes. If, on the other hand, he desire to lay down a permanent pasturage, then phosphates—as bone-dust, &c. —are of great value. The extended notice of the effects of sewage matter, already given, will form a general guide for the application of all kinds of manure; because, although sewage water is so dilute, yet, as it contains all the essentials of plant-growth in a greater or less degree, it is typical, in its results, of the action of all other kinds of manure.

Drainage of pasture lands cannot be too carefully attended to, not simply for the purpose of drying the land (because an excess of that method would be its ruin), but rather because a regular percolation of moisture should be kept up. It has been seen, for example, that the application of 3,000, 6,000 and 9,000 tons per annum of sewage, *carefully drained off*, is of the highest value to the grass crop; but if that sewage had been allowed *to remain* on the land, the crop would have been ruined. Hence, in the west of England, in Piedmont, Lombardy, and other countries, irrigation is largely employed. But the water used is drained off as speedily as possible, without doing so to the injury or removal of the soil at the roots of the plants; hence all the valuable substances in solution of the water are constantly brought, in fresh succession, into contact with the roots of any crop to which it is applied.

It must also be remarked, that a hay crop greatly exhausts the soil. It is essentially a very close crop. Every root is in contact with its neighbour; and when the grass is converted into hay, an immense quantity of mineral and other constituents of the soil are removed from it at each cutting. For example, we have, for the last four years, carefully noticed the produce, as grass and hay, of a four or five-acre field. In expectation of a railway company purchasing it, no manure has been applied during that period. In each year the crop has deteriorated, both in height and quality, to such an extent that it might be accurately measured, in degree, by appearance and before cutting. In the present year, although one of the best that has occurred during the last thirty years that we have crossed the field, the crop of hay was scarcely worth gathering. In fact, the greater portion of the crop was buttercups.

In regard to hay-making we have little to say, because it is an operation of a purely mechanical character, and now so largely carried on by the use of machinery in place of human labour. We have already warned the farmer of the danger of stacking his hay in a damp condition. We are now writing at the end of the hay season; and have little or no doubt that at least ten stacks of hay in our neighbourhood will be on fire by the end of September. Of course, attempts will be made to fasten the results on suspected incendiaries; but, should it be our ill-fortune to be on the jury at the trials of such *suspecta*, we shall have no hesitation in "starving out" the rest of our jury brethren; convinced that, however possible incendiarism may be, spontaneous combustion of such stacks, put up in wet weather, is far more probable and possible.

We now dismiss the subject of grass crops, in which we have included grain and grass crops proper, because they both belong to the *Gramineæ*, or grass. We next proceed to the peas, beans, &c., that are, botanically, included in the *Leguminosæ*, or Pod order.

POD OR LEGUMINOUS CROPS.

The crops raised from the leguminous or pod-bearing plants are of great importance as food, both for man and the lower animals. Distributed throughout the world, the *Leguminosæ* number about eight thousand species, besides the varieties into which those species are divided. They are either herbs, shrubs, or trees; as, for example, the pea and bean, acacia, broom, laburnum, &c. Clover, &c., we have irregularly classed with the grasses; because, as we are writing for practical, rather than purely scientific persons, the convenience of those first-named is most consulted by the plan we have adopted.

The leguminous, pea-flower, or pod-bearing order is so extensive that botanists have subdivided it into three groups, called, respectively, the *Papilionaceæ*, or those that bear butterfly-looking flowers, and include most of the excellent plants belonging to the order; the *Cæsalpinieæ*, that furnish logwood and other dye-woods, &c.; and the *Mimoseæ*, which afford gum-arabic, catechu, &c.

So far as temperate climates are concerned, the sub-order *Papilionaceæ* is the most important, because it includes the pea, bean, lentils,

&c., all plants of use in respect to their seed as food in temperate climates. But, besides these, the *Papilionaceæ* yield the different varieties of clover, broom, gunn hemp, indigo, liquorice, gum tragacanth; the ground nut, that produces a valuable burning oil; ebony, rosewood; the Tonquin bean, sanders-wood, used in dyeing; balsam of Peru and Tolu; with many other vegetable products of great commercial value, but too numerous to be here detailed.

From the *Cæsalpinieæ* division of the Pod order, we obtain logwood, divi pods, used in tanning; sappan-wood, used in dyeing; senna, a valuable medicine; tamarinds; gum copal; the locust-tree wood; balsam of copaiba; cam-wood, used in dyeing Bandana handkerchiefs; carob pods, used as food for cattle; and other important products.

The *Mimoseæ* produce us gum-arabic; catechu, used in medicine and tanning, &c., &c.

It will hence be seen, that the pod-bearing order of plants, or *Leguminosæ*, are of the highest importance in daily life. But, as already intimated, only one division is usually cultivated in our climate.

In a chemical and agricultural point of view, the *Leguminosæ* stand pre-eminently forth as the most nutritious of any kind of vegetable product. By reference to a table at p. 363, *ante*, it will be seen that, whilst wheat only affords about 13 per cent. of flesh-forming substances, peas and beans give us about 24 per cent.; accompanied, at the same time, with about 36 per cent. of starch, or heat-giving matter. It hence follows that a pea or bean crop must largely accumulate from the soil, or air, a considerable quantity of nitrogenous, carbonaceous, and mineral matter.

A great variety of both peas and beans is cultivated. Botanically, peas are known as belonging to the genus *Pisum*, and beans to that called *Faba*. The ordinary bean is generally classed, in its first varieties, as the *field* and *garden*; but so many of these varieties have been produced, that such distinctions are of little real value. Ordinary beans are, at present, mostly known as Mazagan, Windsor, Genoa or long pod, royal dwarf, horse or Scotch, tick, &c. For an early crop, these field beans should be planted in November; and then they will be fit for use at the end of May, or beginning of June following. The Early Mazagan comes earliest to fruit if so planted. The best method of planting is that of drills three inches deep, and six inches apart in the rows, leaving three feet between the rows. In the intervening area, cabbage or other green crops may be grown, so as to economise the land as much as possible.

Kidney or dwarf French beans are rarely grown, except by the market gardener. They are divided into several varieties, and, as a rule, should be sown in the beginning of May, on a light, rich, warm soil; and towards the end of that month, or the beginning of June, they may be sown in a more exposed situation, and by this means a regular succession can be obtained. The drills should be from two to three inches deep, and the rows two feet apart.

Scarlet and other running beans have been much cultivated of late years on small farms; and for the garden of the horticulturist or private individual, they are not only useful as a vegetable crop, but also ornamental. The ground for running beans should be thrown up in trenches. Ammoniacal and lime manures are of great value; and we have found old mortar and soot, mixed together, of great use for the purpose. At p. 424, *ante*, we have recounted some experiments that we have tried on the growth of scarlet-runners on clay soil. The tops should be pinched off of all beans when they have attained what may be called their average height, because then the vital action of the plant is expended in sending out side and prolific shoots, flowers, and pods.

Of all soils, those chiefly of a chalky, calcareous, marly, and consequently, in each case, of a lime nature, are best for peas, beans, and other leguminous crops; and hence we have frequently called such "lime crops" in previous pages. Good drainage, so as to free the root from excess of moisture, is also essential, as we have mentioned at p. 424, *ante*, in recounting the experiments just referred to. A good width between each row is desirable, so as to give plenty of air and light; and the intervening space may be utilised by growing cabbage, spinach, and a variety of other green crops. Even a distance of six feet between each row is advantageous; and this apparent waste of space, if utilised by a green crop, is more than counterbalanced by an enlarged production of beans, no matter what variety is cultivated. Sometimes peas are sown with beans, for the purpose of acquiring pea-straw to bind the bean-sheaves; but we do not admire the practice, and cannot consider it as generally desirable.

Peas.—Belonging to the Leguminous order, peas are ranged under the genus *Pisum*. The usual species is the *P. sativum*, of which there are numerous varieties. They grow best on calcareous soils, like beans; and we have seen some excellent crops in Kent, grown in the field.

The pea crop should have a rich and deep soil, well trenched, and supplied with thoroughly rotted manure. A first sowing should be made in November for early peas, a proper selection being made in respect to seed. The second sowing may be made in February, of course in the absence of frost; and subsequent to that, sowing successive ones should be followed every three weeks, to the beginning of June. For peas of moderate height, an interval of four feet between the rows, and for high-growing peas one of five to six feet, is desirable.

For reasons already assigned in respect to beans—that is, the necessity of plenty of air and light—no ground need be lost, because other and short crops, as spinach, &c., may be sown between the rows; and, at the same time, the total crop of peas even becomes larger.

In respect to manures, those just given regarding beans are equally applicable in the case of peas; but liquid manure is desirable for the pea crop. Freedom from excess of moisture is an essential condition for prolific growth. Farm-

yard manure, chalk, or old fine-powdered mortar, spread on the land after ploughing it, subsequent to the reaping of a grain crop, will be an advantageous mode of procedure. Drilling and dibbling are the proper methods of pea-sowing; and it is advisable that hoeing should be had recourse to, for the purpose of keeping down weeds.

We avail ourselves of the lists of an eminent seedsman, and most successful horticulturist, for the following and other succeeding names of seeds for the use of the farmer, giving, at the same time, the height to which each variety grows.

Earliest.

	Height in feet.
Beck, Gem, Royal Dwarf or Tom Thumb, a good bearer; good for forcing, and very early	1
Dillistone's Prolific, supposed by many to be identical with Sutton's Ringleader, and Carter's First Crop; it produces a good crop early in June. Dr. Hogg, speaking of this pea, describes it as the best early in cultivation	2
Early Emperor, Early Conqueror, Early Kent, Morning Star, Wonder, or Prince Albert	3
Essex Rival, the best flavoured early pea, and very productive	3½
M'Lean's Little Gem, the earliest wrinkled variety known, coming in at the same time as Sangster's No. 1, and equal to Champion of England in flavour; grows only one foot high, requires no sticks, and may be sown in rows at eighteen inches apart. One of the most useful kinds of *wrinkled* peas	1
Poynter's Early, a very productive early pea, of superior flavour. In 1866, this was the earliest pea gathered	3
Sangster's No. 1, Daniel O'Rourke, Isherwood's Railway or Early Champion	3

Second Crop.

Advancer, a new dwarf blue, wrinkled marrow, of fine flavour; the earliest and best of its class	2
Auvergne, prolific, and of good quality	5
Bishop's New Dwarf, long-podded, and very prolific	2
Dickson's Favourite, or Cotterell's Wonder; pods long; a good bearer	5
Early France or Double-Blossomed	3
Fairbeard's Surprise	3
Harrison's Glory, with large pods, and bearing abundantly	3
Harrison's Perfection; white, but otherwise similar to the "Glory" variety	3
Harrison's Royal Blue; perfectly distinct variety; bright glossy foliage, with an abundance of scimitar-shaped pods, and well filled	3
Princess Royal, a distinct white variety, producing an abundance of very large well-filled pods	2½

	Height in feet.
Rising Sun, an early green marrow; dark-green pods, and an abundant bearer	3½

General Crop.

Alliance, or Eugénie, the earliest white marrow; pods large, very prolific, wrinkled	2½
Blue Scimitar; good variety, pods large	3
British Queen, Ward's Incomparable or Carter's Victoria, of fine flavour, and wrinkled	6
Buckley's General Wyndham, with long pods, producing from seven to nine peas in each; an abundant bearer, wrinkled, and bearing till very late in the season	6
Burbridge's Eclipse; one of the best dwarf peas grown, and very rich-flavoured	2
Champion of England (Fairbeard's); excellent bearer, good-flavoured, wrinkled	4
Champion of Scotland; very prolific, and wrinkled	5
Fairbeard's Nonpareil; very prolific, fine flavoured, and wrinkled	4
Hair's Dwarf, Green Mammoth; one of the finest of Marrow peas, wrinkled	3
Knight's Dwarf, Green Marrow, wrinkled	3
Knight's Tall Green Marrow, wrinkled	6
Lord Raglan; large, abundant bearer, wrinkled	3
Mammoth Fall, Green Marrow; an abundant bearer	6
Ne Plus Ultra, Payne's Conqueror, or Jeyes' Conqueror; very large pods; an abundant bearer, fine flavour, and one of the finest peas grown, wrinkled	6
Paradise Meadow, Champion of Paris, or Excelsior Marrow; long pods, abundant bearer	4
Prince of Wales; the most prolific white wrinkled pea in cultivation, producing pods near the ground to the top, and wrinkled	4
Ringwood Marrow, or Flanagan's Early; very prolific	5
Veitch's Perfection; long and full pods, with excellent flavour, abundant bearing, wrinkled	3½
Waterloo, or Victoria Marrow, Gibbs' Defiance, Early Goliah, or Magnum Bonum; pods very long, producing seven or eight peas in each	6

The preceding list is as complete as can be made of the present choice varieties of peas, either for the agriculturist or horticulturist. Other varieties, however, are to be met with; and we have selected the preceding, because, from some considerable experience, we can fully trust the statements and judgment of Mr. B. S. Williams, of Highgate, near London. At the same time, whatever variety is chosen, the greatest care should be taken to ensure success in the ground by draining, manuring, trenching, &c., as already advised; and also that such a selection of ground be made as shall suit the requirements of the crop.

ROOT CROPS.

Under this head the farmer includes a considerable variety of crops in a manner that is not in accordance with the teachings of modern science. For example, we have pointed out, at p. 376, *ante*, that potatoes do not form the root of the plant, but, on the contrary, are simply an extended part of the stem; and the same may be said of many of the crops grown in rotation on the farm other than those of the grass tribe.

But these root crops are of essential importance on the farm, whether as food for man or animals. They include turnips, mangold-wurzel, beet, carrots, parsneps, potatoes, &c.; and these are too familiarly known—at least by name—to all our readers, to require a word on our part for the purpose of expressing their general value.

The greater portion are largely constituted of water. Indeed, the crops now under review range, in respect to the amount of water they contain, from about 70 to 90 per cent. of that liquid, possessed as an essential part of their constitution. It requires no science to exemplify this fact; for simple pressure of the finger on a slice of either a carrot, turnip, or potato, is sufficient to show how much water enters into the constitution of these plants, or, rather, of their valued products.

In respect to *Turnips*, they may be ranked as of the greatest value for food of oxen, &c.; and hence they are generally a crop of every farm. The varieties are very numerous. The species belongs to the *Brassica* tribe, in which the cabbage and a great number of coleworts are also included. The genus, &c., are included in the order of *Cruciferæ*—all noted as the highest efficient anti-scorbutics; and hence largely cultivated in all civilised countries. The *Brassica rapa* embraces the common white turnip, and the *Brassica campestris*, the Swede and other varieties.

A good loamy soil, free from excess of water, but not naturally dry, best suits turnips. A judicious admixture of sand, clay, and calcareous soils, where possible, affords an excellent soil for turnip growth; whilst sandy soils, *per se*, are too porous, allowing the escape of nearly all the moisture; clay soils are too retentive and close in texture; hence the advisability of, as far as possible, so mixing or manuring the soil, as to produce a proper source of nutriment and support to the turnip crop.

Another point which is essential, and that we have already frequently urged on the attention of the farmer, is a good degree of pulverisation of the soil. But, generally, turnips succeed a grain crop, and, therefore, the ground ought to be, after ploughing, in good condition for the turnips. As drainage of superfluous moisture is so desirable, a question arises—Which is the best mode of culture, the flat or ridge system? We have no hesitation in adhering to the latter. But, in all cases, judicious attention should be paid to the circumstances of the soil in respect to the distance between the rows. We have already urged, in reference to all crops, the absolute necessity of an abundant supply of air circulating between, not only each row, but each plant; and hence, on a rich soil, it will be impossible to grow a good crop too thickly sown, or too near each other in the rows. But if the distance between the rows be too great, waste of ground will, of course, result; and should an amount of turnip-product be stimulated by the application of forcing manures, the value of the bulb as a food-product must be lessened, because it will be highly porous, the pores being filled with water; and, practically, it will approach to a simple sponge, holding water, with but little nutritive properties. In this, as in many other cases, a middle course, guided by experience, or a chemical analysis of the land, will be decidedly the safest.

We have analysed turnips too stimulatingly grown, that had not one-eighteenth part of their weight as solid matter, all the rest having been water. But some advantage may rest in this if the farmer chooses to make the turnip act as a pump, for the purpose of withdrawing water from the soil, and of so assuaging the thirst of his animals. But we imagine it would be cheaper to buy a pump rather than turnip seed for effecting his object; because a pump may be made to answer its purpose, while a turnip crop may fail to do so.

The varieties of turnips are very great. For horticultural purposes, as for garden grounds, an authority recommends Chirk Castle Blackstone, which is very hardy, sweet-flavoured, and a valuable winter variety; Red Top American Stone, which fruits early and keeps well; besides the American Strap-leaf, white, quick in growth; Early Dutch, a good garden variety; Early Stone; Orange Jelly, or Golden Ball; Snowball, which may be sown for first and last crops; Yellow Dutch; Yellow Malta, and Yellow Scarisbrick, or Altrincham.

Amongst the agricultural, or field varieties, the following may be enumerated, gathered from the able authority just quoted:—

Barrel Green, a fine kind; Devonshire Grey Top-stone, very large; Eclipse Yellow (Waite's), a purple-topped, fine hybrid; Globe Green, medium in size, hardy and solid; Pomeranian Globe Green, white, large, and fine; Red Globe Green, white, with red top; White Globe Green, large and fine; Dale's Hybrid; Norfolk Green, Red, and White; Orange Jelly, and Scarisbrick Yellow, previously named; Scotch Yellow Green, and Purple Top, both hardy, solid, and sweet; Stone or Stubble, a useful kind to follow corn crops. Amongst the Swedish, the varieties are numerous, as the Purple Top, East Lothian, Green Top, Golden Melon; Skirving's Improved, which is large and fine; Jeffries' Sussex Purple Top; Matson's Purple Top; Laing's Improved; River's Stubble Swede, good for late sowing; Sheppard's Golden Globe, and Marshall's Improved. The Tankard Green, Red, White, and Yellow; and the Yorkshire Paragon, close a long list of valuable varieties of turnip seed or crops.

In respect to manures for turnip, guano is highly serviceable, with or without phosphate as superphosphate, bone-dust, &c. A great point

is to keep the ground in an open condition, as regards the porosity or friability of the soil.

But despite all possible vigilance in all these respects, the turnip is subject to two attacks on it that may completely ruin the crop. One is that of the Turnip-fly, the *Haltica*, or *Altica nemorum*, a species of beetle, or *Coleoptera*, and belonging to the *Phytophaga*, or leaf-eating tribe. In the margin one of these troublesome insects is represented in its natural and a magnified size. "They feed upon plants both in the larva and in the perfect state; and many of them do great damage to crops."

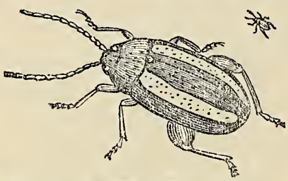


Fig. 340.—The Turnip-fly.

Such is true in respect to the entire tribe; but "the most destructive of all is the turnip-fly, which confines its attention to the leaf of the turnip, and soon entirely removes, in the youngest stage of the plant, all vestige of bloom. Its name is derived *(Altica)* from its jumping powers, the posterior thighs being thickened to enable it to perform that feat successfully."

Numerous plans have been proposed to obviate the destructive effects of this insect, whether by external washes of all kinds, or stimulated growth of the leaf to a point when the ravages of the fly become of little harm; but we cannot mention any plan that may be implicitly relied on. Amongst other methods is that of sowing mustard between the ridges of turnips, and letting the fly feed upon the leaves of the former plant. Abundant manuring, and a plentiful supply of seed, at all events, are sensible precautions; because they will, at least, so increase the amount of crop produced that the balance of chances will be in favour of the farmer. The addition of ashes, spreading of road dust, and other methods by which an external hindrance to the progress of the insect is effected, have all proved more or less of value.

Another injury to the turnip crop is a tendency to a disease called "finger and toe," in which excrescences, like these organs, project laterally from the bulb; and another disease, called "anbury," in which watery excrescences grow on the outer surface, the globe form of turnip being that most affected. For our own opinion, we look upon this disease in precisely the same way as we should on certain scrofulous affections of the human subject. And this view is upheld by the fact, that such varieties of turnip as grow fastest are the most liable to such attacks; indicating, as we think, that their nutrition does not keep pace with the tendency to growth. Again, gravel soils, as destitute of the nutritive matter required by turnips, are those on which the crop is most affected. Lime, abundantly supplied, and every endeavour to increase the nutritive power of the soil generally, seem to be the principle means of preventing or stopping the ravages of the fly, and the abnormal or irregular growth of the turnip.

Mangold, or mangel-wurzel, is a crop that has been largely cultivated of late years as a succulent food for cattle. Practically, it may be considered as identical with beet. The farm kind is the *Beta vulgaris;* whilst the beet used for salad, and grown in gardens, is known as the *Beta hortensis.* This genus belongs to the order *Chenopodiaceæ.* Recently it has been much cultivated in England, and long on the continent, as a source of sugar. One ton of it yields about 160 lbs. of raw sugar, and fifty-five of refined.

The chief varieties of mangel-wurzel are the Elvetham, which is a long red, requiring a deep soil; the Long Yellow, which is very large and solid; the Olive-shaped; the Orange Globe (Fisher Hobb's); the Red Globe, well adapted for shallow soils; and the Yellow Globe, suitable for almost any soil.

Generally the soil should be deeply ploughed for a mangel crop. Farmyard manure, to the extent of fifteen tons per acre, besides a moderate amount (say three) of guano, and two cwt. of salt, are eligible manures. May is a usual time for sowing, and either drilling or dibbling may be had recourse to, the seed being steeped before sowing, to assist its bursting, as the radicle and plumule (see *ante*, p. 375) are produced in it. Being a large but low-growing crop, a width of two feet between the rows or drills is sufficient. In other respects, the methods adopted with turnips are generally applicable to mangel-wurzel. There is this difference, however—mangold can be grown in heavy soils; whilst the turnip, as already pointed out, flourishes best in light, loamy, or calcareous soils.

Kohl Rabi is a crop comparatively new; it belongs to the *Brassica* tribe, and may be considered midway between the cabbage and turnip, not possessing the large bulb-like root of the latter, nor the spreading leaves of the cabbage, but having a large bulging stem between the root and leaves. It forms an excellent substitute for the Swede turnip. It is hardy, resisting the attacks of insects, and the effects of adverse seasons, and is very nutritive for cattle. There are, at least, two varieties, and they may be grown in almost any kind of soil. The manure may be that of the farmyard. The seed may be sown in flat drills, the plants being afterwards singled out; but perhaps the best plan is that of first sowing the seed in beds, and then transplanting the plants on their attaining a height of six inches. The seed may be sown in April or May, if in drills; or in February or March, if in beds. The green variety is large and early; while the purple is smaller than the green.

The carrot belongs to the *Umbelliferæ* order, of the genus *Daucus*, the *D. carota* being the species used for man and animals. The chief varieties are the Altrincham, which is large and red; the Belgian, White and Yellow; and the Surrey Long Red, which yields good crops. A finely-pulverised soil, of considerable depth, is necessary; and the ground should be prepared by abundantly ploughing in well-rotted stable manure. Sowing takes place in March, in drills about eighteen inches apart; and, as the plants grow, they are transplanted singly, at a distance

of six or eight inches each. Careful weeding is necessary, and the seed should never exceed a longer growth than that of being collected in the preceding year. Parsneps belong to the same order as the carrot, the *Pastinaca sativa* being the species grown, of which a good variety is the Large Guernsey. Like the carrot, it forms a rotation crop after and before corn crops. The instructions just given, generally in respect to the carrot, are equally applicable in the case of the parsnep.

The potato is an important "root crop" of the farmer; although, as already pointed out, it is the *stem* of the plant, and not the root, that constitutes this article of food for man and animals. The species cultivated for this purpose, is the *Solanum tuberosum*, belonging to the order *Solanaceæ;* but the varieties of which are very great, and continually increasing, yet also dying out, or disused.

As an article of food for man, it will be seen, by reference to p. 363, *ante*, that the potato stands very low in its heat-giving and flesh-forming properties, containing but 15½ per cent. of starch, only 1½ per cent. of nitrogenous matter, and very nearly 73 per cent. of water. Hence, to obtain an adequate amount of nourishment for man, four times as much, in weight, of the potato would be required to afford an equal amount of starch, as is present in wheat; whilst, in its power of forming flesh, the wheat is nine times, nearly, more valuable than the potato. But the latter, after all, is enormously consumed, as an article of diet, in temperate climes, just as rice is in tropical countries. Hence the growth of the potato is a matter of considerable importance in agricultural pursuits.

The varieties, as already stated, are large in number; and many of them are only suited for certain soils. A heavy clay soil, unless lightened out with sand, lime, &c., and pulverised, is absolutely unfitted for the growth of the potato. The finest that we have eaten have been grown in the calcareous or marly soils of Kent, which present every condition that is required for the growth of the tuber in its most luxuriant and perfect form. In rotation it is generally sown, like some of the preceding, between two corn crops. Farmyard manure, to the extent of twenty-five tons per acre, may be used. Guano is also used; but it has been held, in some quarters, that too heavy manuring leads to disease, which, as far as we have noticed, seems rather to be an accompaniment, more generally, with a wet condition of the land, whether that be highly or slightly manured. The seeds are sown about three or four inches deep, in drills two-feet-six apart; the sowing being so managed, that at least a clear foot shall be kept between the plant in the drills. In some parts where seaweed can be obtained, its application is attended with much benefit. This plan is followed on the coasts of Kent, Lancashire, and Cornwall, where some of the best potatoes are grown that this country can produce.

According to the opinion of some writers, it is desirable that the seed shall have well sprouted before setting; and hence, in Lancashire, the growth of the stem is encouraged by keeping the seed in a dry warm place, until the bud has reached a length of at least an inch. The sowing then takes place about the second week of April.

Some of the latest recommended varieties of potato, at all events for garden sowing, or for the use of man exclusively, and commanding the highest price for seed, are—the Ash-Leaved Kidney, which is very early, and has an excellent flavour; Myatt's Improved Early Ash-Leaved; Daintree's Seedling; Early Shaw, which is prolific; Dalmaboy, which is early; Early Oxford (Loden's), one of the best varieties grown; Fairbairn's Pink Seedling, which is an excellent variety, and remarkable for productiveness, beauty, and size; Handsworth's Prolific, the earliest variety in cultivation; Lapstone, or Haigh's Kidney, early and very prolific; Mona's Pride, a very superior early kidney, said to be the best of any; Royal Ash-Leaf, remarkably early and productive; Victoria Early, the best early round potato, remarkably productive, affording thirty to forty, and even fifty tubers at one root, of good flavour, and excellent for frame-work; Waterloo; Wheeler's Milky White, pronounced as the best potato for the mid-season, being very white, and of excellent flavour; York Regents, &c., &c.

Potatoes adapted for field culture are also of several varieties; such as Scotch Black, London Blue, the Common Yam, Irish Lumpers, with many others too numerous to be here mentioned. In fact, as already stated, the varieties, now very abundant, are constantly increasing, and put out of use those previously esteemed as the best.

It may be naturally thought that an opinion should be offered as to the cause and nature of the disease of the potato, which has, in former times, all but entirely ruined the crop, and spread the utmost distress and famine in our island, whilst yearly it appears to a greater or less extent, often threatening a serious outbreak in the land. We, however, are inclined to think that, whilst in certain districts special causes may exist that seem to be of a general character, though occurring at places far distant simultaneously, yet that the real cause of such a visitation universally in any country must be ascribed to far wider influences. Precisely the same argument holds good in respect to Asiatic cholera. It is certainly more virulent at one time than at others; but this cannot be traced to the heat of a season exclusively, but rather to the bad condition of air or water that all humanity breathe and drink respectively. It is quite certain that this latter disease is within the hands of man to determine its limits; for that was plainly evidenced in the East of London, in 1866. When, it being discovered that bad water was the cause of fearful mortality from Asiatic cholera, instant means were taken to remove the cause, the effect, as if by magic, ceased, cholera not appearing again in the same year; when, if the circumstances of the season had been the cause, it certainly should have been more prevalent.

Travelling, chiefly for geological and botanical researches, in the year of the celebrated potato famine, and conversing with both large and small farmers, in all parts of our island, at that period and since, we have come to the conclusion that no *universal* cause has yet been discovered, however some causes have been satisfactorily arrived at in certain localities, that it has been endeavoured to prove were everywhere active. We shall, therefore, entirely refrain from further expression of opinion on the matter, and rather proceed to detail facts that cannot be denied, and that are universally present in the conditions of the "potato disease" now alluded to.

All starch plants have, as an essential constituent of their substance and mechanical constitution, cells, called starch cells, which are characteristic of the presence of that compound (see *ante*, p. 362). They greatly vary; so much so, indeed, that the various kinds of starch, as of wheat, rice, the pea, &c., can be accurately determined by the microscope, and easily distinguished from each other. Thus, in Fig. 341, the starch cell of the ordinary potato is

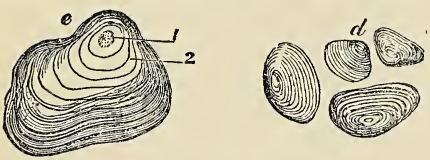


Fig. 341.—Starch Cell of the Potato.

represented. *d* illustrates the potato starch cell of medium size, flattened and with well-marked lines; whilst *e* indicates those cells more highly magnified, so as to show the nucleus of the cell (1), and the line-marks (2). In distinguishing the starch cells of different plants, or their products, the size, figure, and markings are chiefly relied on. Now, as is well known, these cells are insoluble in cold water; hence it is impossible to make "starch" for the laundry except by boiling water, which bursts these cells open, and allows the outward passage of the starch matter, which is ordinarily enclosed in a kind of skin. One of these opened cells is represented in the margin, with the envelope broken. But the potato starch is distinguished from some other starches by its large size, the irregularity of its outline, and the flattened figure that it possesses, which much resembles the form of a lens. The plaitings of its surface are very distinct, as is also the double hilum, marked in Fig. 341, by the number 1. When the potato is in a healthy condition, the arrangement of these cells may be readily observed by cutting a thin slice, and placing it in the microscope. The appearance thus presented is shown in Fig. 343, in which the small ovals are the starch cells, separated into compartments by a kind of wall, *a*.

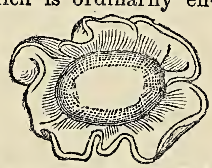


Fig. 342.—Starch Cell opened.

The following illustration refers entirely to healthy and ripe potatoes, such as are considered

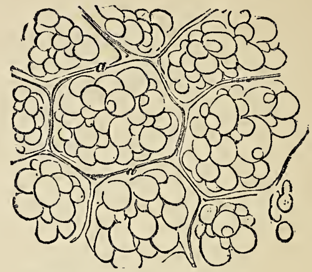


Fig. 343.—Potato Starch.

fit food for man and the lower animals. We have at present only referred to the breaking-up of the starch cells by heat alone; and hence the mealy or flour-like appearance of a good potato properly boiled.

But both germination and putrefaction break up the starch cells, and in a similar manner. Thus, in the following cut is illustrated a slice

Fig. 344.—Diseased Potato.

of a potato undergoing growth, or in a state produced at the commencement of the "potato disease." The form of all the starch cells, except those resembling and shown by *a*, is lost. The cell walls have been broken up, and no sign therefore (with the exception just named) is present of their existence. The starch, in the growth of the healthy potato, has gone to serve the purposes of feeding the incipient plant in the manner already explained at p. 443, *ante*. But in the diseased potato, the cells are broken up into a confused mass, that indicates putrefaction rather than healthy germination.

Now, chemically, there is very little distinction between healthy decomposition and putrefaction. For example, if a man eat and digest bread, almost precisely the same *chemical* changes take place in his stomach as if the bread were allowed to putrefy. But, physiologically, the difference in the process is very great. During digestion, the bread becomes converted into all the various constituents of the animal body; that is, it enters into such new forms as preserve vitality. Just so with the potato. If the starch only goes to supply the healthy-growing plant, it produces shoots, leaves, flowers, and

tubers, and its decomposition becomes a source and food of vital action. It loses its mechanical form of the starch cell it first had, but goes on to produce others of a precisely similar character.

In disease, the starch diminishes, not to produce new forms of vegetable life in the shape of new starch cells : on the contrary, whilst losing its own form, it tends to produce others of the lowest kind of vegetation—namely, *fungus*, commonly typified in the mushroom, and the vegetation attending dry-rot. In the following cut the condition of a diseased potato is illustrated.

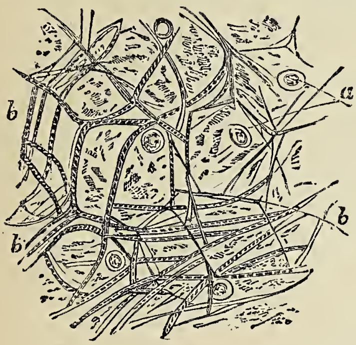


Fig. 345.—Diseased Potato.

a represents an isolated starch cell as yet unaffected ; whilst *b* indicates the presence of "potato fungus," an invariable attendant of the potato disease.

We thus present some of the leading facts of the potato disease—facts that are established by chemical and microscopical investigations, and that can be readily verified, in respect to the latter, by submitting any specimen of an unboiled potato, cut into as thin a slice as possible, to an ordinary compound microscope. It is, therefore, within the reach of any of our readers to examine their own crops, and should disease be suspected, to at once detect its presence.

For reasons already assigned—that is, our incapability of satisfactorily explaining the cause of the disease—we forbear to enter into any speculations that might be reasonably founded on the facts just related. It may, however, be stated, as a matter of certainty, that fungus matter will propagate itself with alarming rapidity in plants and animals. It is hence possible that an exceedingly moist state of the soil, what is called *muggy weather*, and the presence of a large quantity of rotted dung on a field, may all combine to produce, by the propagation of fungus, disease in the potato, producing fungus also *in* it, derived from the fungus external to it. Perhaps an incident of personal experience, that occurred very recently, may be of some service in its relation to our agricultural and horticultural readers.

Perceiving several plants of sweet-peas and the common scarlet-runner becoming sickly, they were pulled up by the roots; and the peculiar appearance and smell of fungus was at once evident. The top soil was well pulverised; but beneath that lay a bed of adhesive wet clay. The soil was mixed with some *soot*, and the plants returned to the place in which they had previously been. In a few days they grew vigorously, and, on again taking them up, it was evident that all fungus had disappeared, and they became in luxuriant bearing.

The reason that we applied soot was not for the sulphate of ammonia that it contained as a manure (see *ante*, p. 391), but because we considered that the carbon of the soot (see *ante*, p. 356) is an invaluable antiseptic; that is, it prevents putrefaction and fungus growth. Thus, if a stake in a hedge or a gate-post be first charred, so as to convert all its external part into charcoal, and it be then inserted in moist ground, it will last five times as long as the same wood uncharred. Many of our practical readers are well acquainted with this fact; and from the knowledge of it, and also of the antiseptic power of the carbon, so largely contained in soot in the most advantageous form of an exceedingly fine powder, we adopted the plan, with the results just related.

How far mixing soot abundantly with the manure applied to the potato-field, on the large scale, attended with deep ploughing, good pulverisation, and draining, would answer as a universal preventive of potato disease, of course cannot be ascertained without extended experiment. Should any of our readers be inclined to follow the plan we have mentioned, we should feel deeply obliged by hearing from them in a letter addressed to us, to the publishers of this work, marked outside—"To be forwarded at once ;" and if the results obtained should justify any further notice, subsequent editions of this volume will be accompanied with a detail of such experiments, &c.; for they would, if successful, be of the highest importance at home and abroad.

The *Brassica*, or cabbage tribe, affords a numerous variety of species, some of which, as the Turnip and Kohl Rabi, have already been mentioned. They are exceedingly numerous, and are ranked under the head of *Cruciferæ*, or bearing flower of a cross-like form. The order *Cruciferæ*, however, includes many other plants besides the *Brassica* tribe; and some of them we shall take notice of hereafter.

For field growth and farm use, for cattle food, the Drumhead, or Scotch cabbage, which may be grown so as to weigh from fifty to sixty pounds per head ; the Swedenburg, which is new, and larger than the Drumhead ; and the Thousand-headed or Jersey cabbage, also called the Cow or Tree cabbage, on account of the height it grows, are of most value for producing on the farm. The latter kind is especially cultivated in the Channel Islands, in the south of England, and Northern France, where it attains a height of from eight to ten feet. The Drumhead is hardier, and can stand frost ; whilst the Tree or Jersey cabbage is less hardy, although standing a mild frost. The nature of all kinds of the *Brassica* tribe, demands that they should be sown in a good stiff soil that has been well pulverised ; hence loam is especially suitable for their

growth. The analysis of the cabbage tribe, given at p. 363, *ante*, indicates that, weight for weight, they contain far less nutritive and solid matter than corn crops; not, indeed, equalling a twelfth part of that of wheat. But turning to p. 347, *ante*, we shall find, that although the *comparative* amount of soil exhausted is small, the *actual* amount is large, because, as in the case of turnips, a larger crop in *weight* can be grown on an acre compared with that of wheat. The latter, however, abstracts one kind of soil constituent, whilst cabbages, turnips, &c., abstract others—a fact made remarkably evident by reference to the two tables given at p. 401, *ante*, where the proportion of phosphoric acid and potash required for one of nitrogen, in most farm crops, is mentioned.

It therefore results, that whilst wheat and other grass crops take silica and ammonia largely from the land, the *Brassica* tribe demands, as a rule, a greater abundance of a different kind of food. Common salt is one especial requisite, and with it superphosphate and guano may be employed with advantage, in the proportion of one hundredweight of salt, and two hundredweight each of guano and superphosphate per acre, sown broadcast. Deep ploughing is also desirable, with good drainage. The best plan is to sow the seed in a bed, and then to transplant it to the field; and although it is common to sow in ridges, and then thin out, the method previously mentioned is far to be preferred. It is universally adopted by market gardeners, who generally know how to make the best of their ground. March is, if mild, a good average time for sowing; but any time for sowing may be adopted, up to August; then pricking out the plants in October, and transplanting in the subsequent spring.

For kitchen-garden produce, "the space selected for cabbage should have a good dressing of rotten dung from an old hot-bed, well trenched, eighteen inches deep. Sow in February, on a slight bottom heat. The cabbage from the sowing will be ready for use in August and September; sow again in April or May, a few coleworts for succession. Great attention should be paid to the time of sowing the principal crop, which should be in the second week in August. If sown earlier than this, many of them will run to seed in the spring. From this sowing they will be ready for planting out by the end of October. Plant in rows eighteen inches apart, and at a distance of one foot between each plant."

Many seedsmen recommend the following varieties for the kitchen garden:—Atkins' Matchless Early, very dwarf; Battersea or Fulham; Cattell's Reliance, which is a fine kind; Colewort, hardy green for winter crops; Early Dwarf York or Barnes'; Early East or West Ham, a good general crop; Early Nonpareil; Early York, a small cabbage, but heading quickly; Enfield Market, or King of the Cabbages; Fearnought (Melville's), a very early dwarf variety; Hill's Incomparable Dwarf, a dwarf and close-growing variety, yet producing a medium-sized head, and that has been described as the best cabbage extant, and "one that will, in time, supersede all others;" Kemp's Incomparable, a fine early dwarf, of good flavour; Little Pixie, a very early small cabbage, but the best flavoured of any; Pearson's Early Conqueror; Red Dutch; Rosette Colewort, very dwarf and hardy; Shilling's Queen, early and compact; Sugar-loaf, a good old variety, and very early; Wheeler's Imperial, a very early, highly recommended cabbage, that should be grown in every garden, and an excellent variety to use where only one kind is grown.

MISCELLANEOUS CROPS FOR THE FIELD AND KITCHEN GARDEN.

The preceding pages have been devoted to a description of those crops on which the farmer chiefly relies for turning his ground to advantage, in producing food on the large scale for man and animals, and the cultivation of which may be termed the chief object of farming. But attached to every farm, there may be devoted, with great advantage, at least from one to four acres of ground, dependent on the size of the farm, on which a variety of smaller crops can be grown, not simply for the use of the household, but for sale at market. In the neighbourhood of all large cities and towns, the kitchen garden may be made a most profitable part of the farm. Indeed, we are acquainted with such places that yield annually, in the neighbourhood of London, a gross return, per acre, far greater than would be sufficient to buy the freehold of an acre of land at some distance from the metropolis. But, practically, distance is now all but annihilated by the cheap and quick transit of all goods to and from any part of England. Hence Cornwall and Devonshire send in their daily supplies to the metropolis of all kinds of vegetables, and salads for table use. Truck-loads of these may be seen flying along the Great Western and other railways, for the use of that cormorant city, London; whilst the railways on the eastern and northern coasts are equally engaged in the supply of fish, cattle, and dead meat; and almost every line in the kingdom is similarly employed to bring milk, cheese, and all kinds of farm and dairy produce, to the same grand centre of eating and drinking.

When it is remembered that the metropolis has a population, at the present, equal to that of the whole of Scotland, the farmer may conceive the extent of supplies that are demanded. To find the population of a nation encompassed in an area never extending further than ten miles from its centre, as is really the case with London; also a place to which every railway of the least importance in England and Scotland has direct access for goods of all kinds, the most remote districts being able to deposit at it their produce, even if 500 or 600 miles off, in less than thirty-six hours; bearing in mind, also, that the inhabitants of that overgrown metropolis have tastes as varied and extensive as the means they possess of gratifying them—with all these facts, we cannot help expressing

the utmost astonishment that a shilling trip from London will, on most of its divergent railways, carry us beyond all extensive market gardens, and plunge the traveller into the comparative wilderness of corn-fields and pasturage. But whilst by no means undervaluing the latter, we cannot help urging the great value and profitable results that would arise to the majority of farms, and especially those of small size, if a portion of the ground was devoted to the market garden. Only those who have both resided in our large towns, and diligently walked through the chief agricultural districts of England, can have any idea of the enormous difference paid by the retail purchaser of vegetables, fruit, &c., between that and the price obtained by the grower. Whilst the pigs are feeding on the apples, cabbages, &c., in some of our southern, south-western, and western counties, the inhabitants of London, old and young, are glad to pay for each at the rate of a 1*d.* or 2*d.* per pound, and sometimes even a greater price, for the same commodities, of far inferior real value, and often unfit to eat. In fact, it is impossible to over-estimate the value that a more extended cultivation of the kitchen garden would produce for the farmer. He has the advantage of having everything ready to hand. He has the plough to turn up the ground; the spare labourer to dig and harrow it; the abundant farmyard dung to manure it; he can choose any particular field from his land for the purpose, without being compelled to rent a special piece at a high rent, as must be done by those who live near town. In fine, he has every inducement to undertake that which, with care and management, may prove the most profitable part of his agricultural pursuits.

After these preliminary observations, we shall proceed to point out some of the best plants suitable for the kitchen garden, and give such hints as, we trust, may be of benefit to our readers. At the same time we strongly urge those of our readers who may be desirous of further information, to select and peruse works more fully devoted to the subject—as the *Cottage Gardener*, by Sir Joseph Paxton; and numerous other works on the subject, that may readily be procured, and the titles learned through any publisher or dealer in new and second-hand books. For our purpose it will be convenient to take the subjects in alphabetical order.

Artichokes.—These plants are of two kinds, although both belong to the same natural order —the *Compositæ*. The common artichoke, or *Cynara scolimus*, is grown for the sake of the eatable head, which much resembles that of the thistle, being, however, larger. They are sown in April, in rich soil, and when well up should be transplanted. In forming a plantation of artichokes, they should be planted early in March, in an open situation, and in rich ground. If propagated from suckers, the straggling tops and roots should be trimmed off, taking care not to remove perfect leaves; and they should then be planted in rows, four feet apart, and at a distance of thirty inches in each row between the plants. They require occasional watering until they have taken root. A succession of crops may be obtained by sowing each spring; the two and three-year-old heads being then produced in the summer. Those planted early in March produce heads in the autumn of the same year.

The Jerusalem artichoke is so called from a stupid perversion of the French word *Girasole*, meaning "turning towards the sun." It resembles the potato in nearly every respect; and is, botanically, known as the *Helianthus tuberosus*, belonging to the order *Compositæ*. It is planted like potatoes, by tubers of a preceding crop. They may be either whole or cut in "sets;" and should be planted in rows thirty inches apart, with an interval of twelve inches between each plant in a row. The remarks already given at p. 451, *ante*, about potatoes, are equally applicable, in respect to manures, soil, &c., to Jerusalem artichokes; but the latter grow in all soils and situations.

Asparagus.—This favourite vegetable is obtained from the shoots of the *Asparagus officinalis*, which belongs to the Lily order, or *Liliaceæ*, botanically. It requires a good rich soil; and should be sown in March. At the expiration of two years the plant may be transplanted. In doing this, the soil is trenched up to a height of three feet, a liberal allowance of well-rotted dung being added as the trenching goes on. The beds should be made about three feet in width, and have alleys of about a similar width between. The proper time for planting is when the buds begin to shoot; and two rows, nine inches apart, should be planted in each bed. The shoots are not proper for eating till the third year of growth; but the great price early asparagus fetches in all markets of large towns, remunerates the grower; besides which, the alleys intervening between the beds may be utilised by planting cauliflowers, small cabbage, lettuce, radish, spinach, &c. One of the best varieties is the Battersea or Giant. Whole fields of asparagus are cultivated to the south-west of London, where the alluvial soil is especially suitable for that purpose.

Beans.—We have already fully treated on the field, French, or dwarf scarlet-runners, and other varieties of beans, at p. 447, *ante*; where the reader will find instructions as to soil, manure, growth, &c., &c.

Beet.—At p. 450, *ante*, beet has been described together with mangold-wurzel. It requires a rich deep soil; may be sown in May, in rows two feet apart, and thinned out in single plants, placed eight inches apart, being kept very free from weeds. Some good garden varieties, recommended by Mr. Williams and others, are—Barrett's Crimson, which has a good colour, and is not liable to fork; Cattell's Dwarf Blood Red; Nutting's Dwarf Red, one of the best in cultivation; Pine Apple Short Top, which has roots of medium size, with a very small top, but with a dark crimson root; Silver or Sea-kale, which, if earthed up, forms a top that may be substituted as a salad in place of sea-kale; White Silesian or Sugar; and White or Spinach, the

leaves of which are an excellent substitute for spinach, and are afforded throughout the summer.

Borecole, or Kale.—This green vegetable belongs to the cabbage or *Brassica* tribe, being a variety of the *B. oleraceæ.* The seed should be sown in March and April, in a rich warm border, with occasional watering in dry weather. When of proper size, it may be planted out at a distance of two feet each way between the plants, in ground prepared with well-rotted dung, and deep; following the plantings with watering until they have well taken root. One variety, called the asparagus kale, affords, by covering the plants with pots, shoots that are an excellent substitute for asparagus. Amongst other varieties are—Buda, Jerusalem, or Russian, all hardy; Camberwell Kale, or Ragged Jack; Cottager's Kale; Curled Variegated (Melville's), which is excellent for garnishing; Dwarfed Green Curled, or Canada, that is very finely curled, and hardy; Scotch Cabbaging, also a hardy variety, like the Siberian and Lapland. Of all varieties, our favourite, as a table vegetable, is the Tall Green Curled, or Scotch, which is at once ornamental in the garden, and delicious on the table.

Broccoli is a favourite vegetable in all large towns for table consumption. It is a variety of the *Brassica oleraceæ*, called *Botrytes*, from the grape-like appearance of the flower. The seed should be sown in April, and again in the middle of May; but different varieties are sown earlier and later. The ground should be well manured, and the sowing be followed as in other varieties of *Brassica*, planting out in rows, in which each plant is distant, in all ways, two feet from another. Watering is essential till the plants take root; and care should be taken not to bury the hearts of the plants. The following, sown in May, will produce the ripe plant in autumn—viz., Dancer's Pink Cape; Grange's Early White Cape, one of the best in cultivation; Hammond's White Cape; Purple Cape, which, if sown in June, will keep up a supply from October to Christmas; and the Walcheren, the best for the general crop, which may be sown from February until October. Amongst varieties for winter, spring, and early summer produce, and sown in the June or July preceding, are—Williams' Alexandra, the newest variety, which is described as a cross between Snow's Winter White and Knight's Protecting, as having large, solid, conical heads, being altogether the finest of white broccolis, and hardy, and coming into use in May if sown in the preceding April; Backhouse's Winter Protecting, perfectly standing the winter; Brimstone or Portsmouth, fine for early spring; Carter's Champion; Chappel's Cream; Cornish White; Dalmeny Park; Dilcock's Bride; Dwarf Russian (Miller's), a very hardy variety; Elletson's Emperor, large and late; Frogmore Protecting (Ingram's); Knight's Protecting; Lake's Superb White; Lee's New White Sprouting; Elletson's Mammoth, having large compact heads; Mitchinson's Penzance, white; Purple Sprouting, very prolific; Snow's Spring White; Snow's Winter White, a very valuable variety; Wilcove's Late White, &c., &c.

Brussels Sprouts is the most esteemed variety of all the *Brassica* tribe for winter use. The soil, &c., are to be attended to as generally directed for all members of the cabbage family. It may be sown in a warm bed, in March, and again in the middle of April, and when of sufficient height should then be transplanted into beds, in rows two feet apart, and with an interval of eighteen inches in the rows. For small gardens, the dwarf sort is chiefly suitable. Amongst the most esteemed varieties are—Dalmeny Sprouts (Melville's), which has a delicious flavour, and should be sown at the end of February, or early in March; Perkin's Improved Sprouts, which produce abundantly on the whole length of the stem; Scrymger's Giant, a superior variety, which grows about two feet high, but requires plenty of room; and the Albert Sprout (Melville's), which is a hybrid between the Drumhead Savoy and the Brussels Sprout, bearing long stems studded with hearting sprouts, and having a top resembling a small savoy.

Cabbages.—The soil, manure, and general treatment of cabbages proper, have already been treated at some length at p. 453, *ante*; where the chief varieties are also detailed for all purposes.

Capsicum.—The pods of this plant fetch a considerable price, for admixture with pickles. It belongs to the order *Solanaceæ;* and the kind cultivated for pickles, and, when dried, for Cayenne pepper, is the *Capsicum annuum.* It may be sown with heat in March, or under hand-glasses, in May. The plants, when strong enough, should be removed into small pots, with heat, but access of air in warm days. When fully established, they may be planted out on warm borders; but, in our opinion, they are better kept in pots, because then they are under full control. A rich soil should be used, and the plants take a considerable amount of water. Amongst the best varieties are the Long Red, and Yellow; the Monster; and, amongst the smaller kinds, the Chili, Bird's-eye, and Cherry.

Cardoon.—The leaves of this plant are eaten as salad. It belongs to the order *Compositæ;* genus and species, *Cynara cardunculus.* The Spanish kind, raised from seed, may be sown towards the end of May, in trenches, prepared as for celery. The plants, when fully up, should be thinned out; and, as they grow, the leaves should be tied up with matting, to blanch them. The method of growing and blanching celery (to be hereafter described), may be adopted for the cardoon.

Carrot.—The treatment of the carrot generally has been described at p. 450, *ante;* and, as it is more of a field than a garden crop, we shall not here further notice it.

Cauliflowers.—In these we find another of the *Brassica* tribe. For an early crop, the seed may be sown in the third week of August; and to be transplanted when well up to a sheltered border. A successive sowing may be made in the early part of February, in a frame, with slight heat, to be afterwards transplanted in deep, well-

pulverised, and rich soil, in rows two feet apart, with an interval in the rows of eighteen inches between each plant. Liquid manure is an excellent stimulant; but the directions given in respect to the soil, manure &c., for cabbages, are equally applicable to cauliflowers. The present esteemed varieties of the cauliflower are —the Asiatic, or Leyden, which are large; the Early Dwarf Erfurt, that also has fine large heads; the Early London, good for a general crop; the Late London; the New Early Mammoth, or Frogmore Forcing; the Stadtholder; Walcheren, &c.

Celery.—This vegetable is of great esteem for a variety of purposes. As a winter salad it is highly valued. To soups it communicates a fine flavour, its seed being often used when the stalks of the plant cannot be obtained. Cut up in small slices, and mixed with mustard and vinegar, it makes an excellent sauce to hot and cold roast beef—a mode of its use but little known in London, but largely followed in the north. No celery that we have tasted equals that grown near Manchester and Lancashire generally, although, near London, some fine celery is produced. Sowing may take place in rich soil, with bottom heat, in February. When the size of the plants, and the state of the weather permit, they may be transplanted to an old dung-bed, at a distance of four inches apart, protected from cold air and frost. When hardened they are to be planted out into trenches of rich friable, or well-pulverised soil, at a distance of six inches apart. As the plants grow, after getting strong, they should be kept continually earthed up; but this should be done only in dry weather, because heavy wet soil would greatly check their growth and flavour. Celery, however, takes water with avidity if grown in the proper soil; and, consequently, the plants should be watered at such intervals as will keep them moderately moist, but not wet.

From personal experience, in trials stimulated by an almost gluttonous taste for the plant, we do not hesitate to class it as the most refractory member of the kitchen garden tribe. Of every plant that grows, of an edible nature, it may be affirmed that celery is one which most determinately exercises a geological selection of soil. We have eaten it in almost every place in England and Scotland that it can be procured, and emphatically declare, that the only places at which a celery epicure can enjoy it, or, indeed, consider it edible, are such as are situated on alluvial soils; that is, such soils as have been left by the desertion of a river of its old natural bed. Thus, in the valleys of the Mersey, &c., in Lancashire, and of the Thames, near London, it is produced in great perfection. But wherever the alluvial condition is absent, the celery is rank, stringy, and perfectly unfit for eating, being only palatable as a flavouring for soup. About twenty years ago, "regardless of expense," we expended all our chemical and botanical knowledge to combat the prejudices of this plant, so far as raising it to perfection was concerned; but had to retire from the battle against nature, completely vanquished; and the same result is doubtless verified by the experience of all our readers who have made similar attempts under the adverse circumstances of unsuitable soil. It must not be supposed, however, that the plant will not grow. That is easily effected; for, in its wild state, it is a common weed, familiar in abundance in our hedges. It belongs to the extensive order of *Umbelliferæ;* genus and species *Apium graveolens;* and, consequently, allied to parsley. Celeriac is a turnip-rooted form of celery, and is very hardy. It does not require earthing up; but, in other respects, is treated like celery. Amongst the most esteemed varieties of both, in present culture, are—the Celeriac, or Turnip-rooted; Cole's Crystal White; Cole's Superb Solid Red; Cole's White Perfection; Hood's Imperial Dwarf Red, a very good variety; Laing's Mammoth Red, which is a large one; the Manchester Champion Red (Dickson's), an excellent variety; Seymour's Champion White; Turner's Incomparable White, very dwarf, and one of the best white celeries; and a new and superior variety, called Williams' Matchless Red, which has a fine flavour, and stands to the end of April, without any tendency to run to seed; it is considered, by competent judges, to be one of the best varieties of red celery that has been brought into cultivation. There are many others, but our space forbids their enumeration.

Chervil much resembles parsley in its growth, &c., and is used for garnishing. There are two varieties, the Curled and Parsnep-rooted, *Chærophyllum bulbosum.* [For sowing, &c., see Parsley.]

Chicory is used as salad; and its roots are much employed, when roasted, as a substitute for, or to mix with, coffee. [For sowing, &c., see Endive.] Its botanical name is *Cichorium intybus*, and it belongs to the order *Compositæ.*

Cress.—Of this salad there are several varieties, as American, Normandy, Australian, Watercress, and the common cress. The Australian is the most esteemed, and the newest. Watercress grows best in running streams, and when once planted, grows prolifically. We planted a small quantity at the top of a hill stream some years ago, in the west of Scotland; and, on visiting the spot about three years afterwards, found that the plant had spread for nearly a mile down the windings of the stream. All kinds of land-cress grow in almost any soil, and the seed only requires putting into the ground in drills, with occasional watering. By successive sowings, the supply may be kept up the whole year, a warm bed in winter being desirable. The American and Normandy varieties are the hardiest. All of them are excellent antiscorbutics; and a more liberal use of them at the table than is now followed, would do much to prevent numerous affections of the scurvy kind.

Cucumbers. — Formerly, cucumber-growing was confined to few hands, and their price enormous. In our younger days, 1*s.* 6*d.* to 2*s.* was an ordinary price for a good frame-grown one. Now the best may be bought in summer-time for 6*d.*;

and, indeed, within the last six or eight years, they have been purchasable at Covent Garden Market, London, during the whole year for that price. Cucumbers and salads are largely imported from abroad; and Cornwall also contributes to supply this country to a great extent. The following instructions are given for the growth of cucumbers, on the authority of one of the most successful growers and prizemen near London.

"In preparing to cultivate cucumbers on dung-beds, it will be necessary, in the first place, to form a seed-bed. For this purpose you must procure a quantity of fresh dung, as much as will be sufficient, after being well fermented, to form a bed about four feet high, and in width and length according to the size of the frame you are about to use. The seeds may be sown in January and February, in pots or pans. The temperature of the seed-bed should range from 70° to 80° [to ascertain which a thermometer must, of course, be used]. As the plants begin to grow, admit air in sufficient quantity to allow them to become strong. When the plants have produced their seed-leaves about half an inch broad, pot them off in twos or threes in a pot close to the sides; and when sufficiently strong, and the pots well filled with roots, carefully turn them out of the pots, and plant on mounds of fine, rich, turfy loam. Being thus planted, give them a gentle watering with a fine rose-pot. The principal object to be attended to, is a constant steady-growing heat in the bed, and that must be effected by applying linings of hot dung sufficiently strong to reinvigorate it. As the plants grow, frequent attention must be paid to stopping, training, and setting the blossoms.

"Ridge cucumbers are but little trouble. Sow the seed on a slight heat. When strong enough, pot them, by twos and threes, in a pot. About the middle of April, dig out a trench, eighteen inches wide, and eighteen inches deep; fill in with dung in a fermenting state to about a foot from the level; then surface over nine inches deep with mould; turn out the plants, and cover with hand-glasses."

The varieties of this delicious fruit are too numerous to be detailed here: we only select such as are most esteemed or recommended, at the present time, by the nursery seedsmen. They are—Barret's Excelsior, a very fine black spine, bearing fruit eighteen inches long, and very prolific; Dr. Livingstone, which has black spines, grows eighteen inches long, and is of a fine dark-green colour; Empress Eugénie, that has slender but handsome fruit; Hamilton's Market Favourite, with fruit sixteen inches long, and of uniform thickness throughout; Hedsor Winter Cucumber, a fine winter variety; Simpson's Incomparable, black and white spine, individually with long fruit, and prolific; Ipswich Standard, good for winter use—black spine, prolific, and a good setter; Manchester Prize, or Turner's Favourite; Pain's New Ridge, equal to a frame cucumber in size, and very prolific; Phenomenon, a first-rate cucumber of the tipped spine class, sixteen inches long; Sharman's Universal, the best winter cucumber; Sion House Improved; Monro's Prolific, or Lynch's Star of the West, an excellent white spine variety; and Telegraph, a fine winter variety. The cucumber belongs to the Gourd order, or *Cucurbitaceæ;* genus and species grown for eating, *Cucumis sativus.*

Endive.—This plant is much esteemed as a salad. It may be sown successively from April to August, in beds like the cabbage; and when the plants are full up, they may be transplanted to drills, fifteen inches apart, and a foot in the drills. Blanching is effected by tying up the leaves as they grow. When full-grown, plants may be preserved throughout the winter for use, by taking them up, and replanting in sand or dry mould, in a shed or cellar, in rows, so as not to touch each other. The leaves are first to be tied up close, and the plant inserted sufficiently deep in the sand that only two or three inches of the top appear above the bed. Endive belongs to the same genus and order (*Compositæ*) as chicory. The grown species is *Cichorium endivia*, and the best varieties, Digswell Prize, French Moss, Curled, and the White Lettuce-leaved Batavian.

Gourds belong to the same order as the cucumber, vegetable marrow, &c.; and the treatment of them generally is the same as that directed for the cucumber. They make excellent preserves and pies, especially if mixed with apples; and the plants are astonishingly prolific. The uses just named, however, seem to be but little known. Some years ago, whilst dining at one of the chief hotels of one of the largest cities in the north, the waiter brought on a dish of boiled gourds, in place of turnips, and assured us he had never heard that there was any difference between a gourd and a Swede turnip; and still less had he learned that gourds make good pies and preserves.

Leek.—This belongs to the onion tribe, including chive, eschalot, or shallot, garlic, &c. Generally the instructions to be given in respect to the onion are applicable to all its varieties. But the leek, being used both for its stem and bulb, should be earthed up as it grows. By this not only will the stem be blanched, but the whole will eat mild and tender.

Lettuce is a salad of which immense quantities are sold during the season; and a succession is kept up by successive sowings, commencing in February, with a bottom heat, and continuing fortnightly until the end of July. The winter crop should be sown in August, and one may be made in October, in a warm frame. The plants, on getting well up, should be removed singly into rows, on rich ground, the latter being essential to produce crispness and good flavour, with large hearts. Blanching is effected on the Maltese variety of the cabbage kind, and on Cos lettuces by tying up the outer leaves a they grow. The plants should be watered freely in dry weather, for they absorb much moisture from the soil. Of the cabbage kind, the several choice varieties are—the Hammersmith Hardy Green; the Large Versailles; Laitue Française; the Malta, or Drumhead; the Neapolitan; Ne Plus Ultra; Stansted;

Wheeler's Tom Thumb, &c. Of the Cos kind—the Alma; Bath; Egyptian Green; Florence, or Green; Moor Park, the best in cultivation; Paris Green and White, &c. The lettuce belongs to the *Compositæ;* genus and species are *Lactuca sativa.*

Melon.—The instructions already given for the cucumber are precisely those that should be adopted in melon-growing. It belongs to the *Cucurbitaceæ:* genus and species, *Cucumis melo.* The varieties of green, scarlet, and flesh-coloured fruit are very numerous. The following are at present esteemed—Malvern Hall, scarlet; Brougham Hall, green; Cocoa-nut (Fleming's), green; Garibaldi, scarlet; Golden Perfection, or Tiley's Golden Ball, green; Green Gage, green; Heckfield Hybrid, green, and has taken many prizes; Incomparable (Bousie's), green; Scarlet Gem (Bailey's), scarlet; Stoke Farm, or Atkinson's, scarlet; Trentham Hybrid, green; &c., &c.

Mustard.—This plant is not only of value for its seeds, so extensively used as a condiment; but also as a "stolen" food for cattle in the fields. All the ox tribe are extremely fond of it; and as it grows readily on any soil, it requires not the least art in cultivation. There are two uses that are but little known in respect to mustard. The seed-pods, which are produced in great abundance, form an excellent pickle; whilst the flowers, when in bloom, attract bees, perhaps as much as any other flower. We are now looking on a patch about five feet square, in bloom; and there are at least 1,000 bees feeding, although we are not aware of any hive being nearer than half a mile. Punctually every morning, however, come in a complete tribe, and spending about an hour or two, leave till the evening. Did we keep hives, a patch of mustard should be provided close to them; and, for about a halfpenny-worth of seed, an almost endless stock of flowers might be ready at hand for the use of the industrious little insects. Mustard belongs to the *Cruciferæ;* the genus and species are *Sinapis alba* and *nigra* (white and black).

Nasturtiums are, whilst beautiful as a garden flower, useful as a pickle. The varieties are tall and dwarf, the seeds of the former being used for pickling, and frequently substituted in households for the more expensive caper. The plant belongs to the order *Tropæolaceæ*, and the genus and species are *Tropæolum*, *Major* and *Minor.* The leaves form an excellent mixture for salads, giving them a warm or pungent flavour.

Onion.—The use of the onion has been universal for ages; and hence we read, in the earliest records of it, leeks, &c. It was first cultivated in rich soil of mid-western Asia, and is now distributed all over the world, where civilised humanity has located. Its value as an article of food is great for those who can bear its flavour, and digest it: the onion is one of the best restoratives that can be had recourse to. We have found that, after speaking at a public lecture—say for a couple of hours—no other solid, nor any liquid, equals it in restoring from mental and bodily fatigue. Hence, perhaps, its enormous use amongst the lower classes, to whom bodily fatigue is a matter of daily and necessary recurrence; whilst, in more refined society, its flavour is rarely omitted in numerous "made dishes."

We have already noticed the chive, eschalot, or shallot, garlic and leek. They all obtain their flavour from the presence of an oil containing sulphur, which, if largely possessed in any variety, makes it very rank to the taste. Onions contain also a considerable amount of nitrogen, and, for that reason, become an eligible addition, in a chemical point of view, to many other articles of food. The different varieties and species are ranked under the genus *Allium;* the large bulbous onion being the *Allium cepa;* the leek, *Allium porrum;* Garlic, *Allium sativum;* and the Shallot, *Allium ascalonium;* and of all these, the last is, to most palates, that chiefly preferred.

Ground intended for onions should have a good dressing of rotten dung from an old hot-bed, and be trenched at least eighteen inches deep. Sow the main crop the first week in March, on a fine dry day; also a few may be sown about the middle of August, for winter and early spring use. Sow broadcast in beds four to five feet wide, with eighteen-inch alleys, or in drills nine inches apart, to be better enabled to keep them clear by hoeing during the summer months. Thin out plants to proper distances, and give them a slight dressing of soot, to prevent insects.

Amongst the most esteemed varieties of the ordinary bulb-formed onion, at present grown, are the following:—The Nuneham Park, apparently a cross between the White Spanish and Flat Tripoli, keeps longer than any other. A crop of ground, twenty by eighteen yards, produced, in one season, 32 cwt. of fine onions, averaging eleven ounces each. Its flavour is mild. Blood-Red have a strong flavour, but keep well; Brown Globe are mild, large, and good for general use; Brown Spanish, or Portugal, are good for a general crop; as are also Danver's Yellow, Deptford, and James's Long Keeping; Silver-skinned are best for pickling; Strasburg are hardy, large, crop and keep well; Tripoli Globe are large, and good for autumn sowing; Welsh Hardy stand the winter well; White Globe are very large, and give heavy early crops; White Lisbon have a mild flavour, and are best for autumn sowing; White Spanish are mild, and generally esteemed.

Parsley is a favourite herb for garnishing; sauces, &c. It may be sown in rows a foot apart, from April to July, on a deep rich soil, and then thinned out, at the rate of six inches distance between each plant. Soot is advantageously sprinkled over it in wet weather, and stimulates the growth of the plant. Transplanting greatly improves all varieties; the chief of which are—Enfield Matchless (Mitchell's), Fine Curled (Myatt's), and the Hamburg or Turnip-rooted.

The *Parsnep* has already been noticed at p. 451, *ante.* The garden kind are sown in March,

in deep rich ground, well trenched, and in rows fifteen inches apart, thinned out afterwards to eight inches. It is necessary to stir between the plants when young, to prevent forking. They may remain in the ground all the winter, and be trenched out as wanted. The genus and species are *Pastnaca sativa;* order *Umbelliferæ.*

Peas have been fully disposed of at p. 447, *ante;* but we shall quote from Mr. Williams, remarks as to the best mode of dealing with them in the garden, at the risk of a partial repetition.

"Peas require a deep rich soil, well trenched, to which add a good quantity of well-rotted manure. For very early produce, a sowing may be made in November: for that purpose, the variety, Dillistone's Prolific, is most useful. The next sowing should be made early in February; and from that time, successive sowings may be made every three weeks, till the end of May. The wrinkled varieties (see *ante*, p. 448) should be sown during April and May; for very late crops, sow the early ones late. They should be sown three to four feet apart; but for the latter growing kinds five to six feet will not be too much. There is no ground lost in sowing peas a good distance from row to row; for, by this means, the sides of the rows will have the full benefit of light and air; and, consequently, a greater number of perfect pods will be the result. Water freely in dry weather. Liquid manure is the best when it can be obtained. A crop of spinach may be successfully cultivated between the rows."

Radish.—This plant is not only to be esteemed for its "root" as a salad, but the pods, also, make a delicious pickle, far beyond beans or cucumber in delicacy of flavour, if properly done. A curious variety has but recently been introduced, and named the *Raphanus caudatus.* Growing, it reminds us of the capsicum plant; the edible part being the red pod, which extends several inches, as the *above*-ground fruit of the plant. It is a native of hot climates; but is readily produced from seed, without the aid of artificial heat. Radishes may be sown, under glass, in December and January; and, for successional crops, every fortnight from February, throughout spring and early summer, on a sheltered border, with a southern aspect. It is well to cover the young shoots with straw, in case of frost. Amongst the varieties other than the *R. caudatus*, just named, are—Beck's Superb Short Top, the best for a general crop; Black Spanish, very hardy and large, for a winter crop; Naples, long, white; Olive-shaped Scarlet, a superior variety; Red and White Turnip; and Wood's Early Frame. The botanical name of the ordinary radish is *Raphanus sativus*, and it belongs to the *Cruciferæ* order.

Rampion.—This so much resembles parsneps, in all respects, that the instructions already given for the latter may be followed in growing the rampion.

Rhubarb is a plant the stalks of which afford the earliest natural vegetable for pastry, in our islands. It may be sown in April, on a warm, sheltered border of rich soil; and the plants are, when strong enough, to be planted deep, in well-trenched and rich soil. Generally, however, recourse is had to roots, that are sold by all seedsmen—at all events, for small gardens. The best varieties are—Linnæus (Myatt's), very early and good; Prince Albert (Mitchell's), very early; Tobolsk, very early; and, perhaps the best, the Victoria (Myatt's), which is very large and fine. The roots are largely used to adulterate the genuine Turkey Rhubarb, for medicinal purposes. Genus and species grown, *Rheum rhaponticum*, &c.; order *Polygonaceæ.*

Salsafy has various uses: its leaves are eaten as salad; the root used in place of the radish; whilst the leaves, boiled, resemble spinach.

Savoy Cabbage.—This variety belongs to the *Brassica* tribe, and is sown in March and April, in beds of rich soil. The instructions given at p. 453, *ante*, in respect to cabbages, are equally applicable to it. Watering should be had recourse to after the plants have been set out in rows, until they are well set. Amongst the modern varieties are—Cattell's Dwarf Green Curled, small, and hearts quickly; the Drumhead, or Globe, which are the largest varieties; the Early Ulm, that are small, and early; Marcellan, that are early, and have an excellent flavour; Mitchell's Green Globe, a large and handsome variety; and a hybrid, the Feather-stemmed, that grows like Brussels Sprouts, and has a delicious flavour.

Scorzonera may be generally treated as directed for Salsafy and Parsneps, for which it is a substitute. It belongs to the *Compositæ* genus, and species grown, *Scorzonera hispanica.*

Sea-Kale, the *Crambe maritima*, order *Cruciferæ*, should be sown early in April, on a rich ground, trenched two feet deep, and well manured. The ground may be divided into four-feet beds, with intervening alleys eighteen inches wide; the mould out of the alleys being used to raise the beds eighteen inches high, which will keep them dry. Two drills should be drawn on each bed in which the seeds are to be grown. Sowing should be thick; and the plants are afterwards to be thinned out to two feet apart. But the seed may be sown in beds, and then transplanted to other beds, formed as above.

Spinach.—This vegetable should be grown in rich soil, and sown from March to the end of June. For winter use, the prickly kind may be sown in August and September. The varieties are—New Zealand; Orach, or Mountain; Red Orach; Prickly, or Winter; and Round, or Summer. Spinach belongs to the order *Chenopodiaceæ;* genus and species, *Spinacea oleracea.*

Vegetable Marrow.—This delicious vegetable belongs to the Gourd order, or *Cucurbitaceæ;* its genus and species being *Cucurbita ovifera.* The method adopted with cucumber, as described at p. 458, *ante*, is to be followed out with the marrow; but we have found that they may be procured in great perfection and number by first digging, in good soil, a hole a foot deep and wide, and filling this with good rotted manure that has been mixed with sand. Four plants, on a bed six feet square, thus treated, yielded a supply for three months for a family. They

should be occasionally watered with guano and water, or liquid manure. The choice varieties are—the Chusan, Custard, Long-fruited Green, and White, and Moore's Vegetable Cream, the nicest and most delicate of all the varieties.

Herbs, &c.—These are, universally, a common article of produce, for home use and sale, in the kitchen garden. Their treatment, in respect to soil, &c., may be generally summed up by stating, that an open, well-pulverised, and tolerably rich soil, with a southern aspect, is that most favourable for growth. The following are those of most general cultivation, with the botanical order, genus, and species.

Herb.	Genus and Species.	Order.
Angelica	Archangelica officinalis	Umbelliferæ.
Balm	Melissa officinalis	Labiatæ.
Basil	Ocymum minimum and basilicum	Labiatæ.
Caraway	Carum carui	Umbelliferæ.
Chamomile	Anthemis nobilis	Compositæ.
Coriander	Coriandrum sativum	Umbelliferæ.
Fennel	Fœniculum vulgare	Umbelliferæ.
Horehound	Marrubium vulgare	Labiatæ.
Horseradish	Cochlearia armorica	Cruciferæ.
Hyssop	Hyssopus officinalis	Labiatæ.
Lavender	Lavendula vera	Labiatæ.
Marjoram	Origanum vulgare, &c.	Labiatæ.
Mint	Mentha virides	Labiatæ.
Nettle	Urtica dioica	Urticaceæ.
Pennyroyal	Mentha pulegium	Labiatæ.
Peppermint	Mentha piperita	Labiatæ.
Purslane	Portulaca oleracea	Portulacaceæ.
Rosemary	Rosmarinus officinalis	Labiatæ.
Rue	Ruta graveolens	Rutaceæ.
Sage	Salvia officinalis	Labiatæ.
Savory	Satureja montana and hortensis	Labiatæ.
Skirret	Siam Sisarum	Umbelliferæ.
Tansy	Tanacetum vulgare, &c.	Compositæ.
Tarragon	Artemisia dracunculus	Compositæ.
Thyme	Thymus vulgaris and serphyllum	Labiatæ.
Tobacco	Nicotiana tabacum, &c.	Solanaceæ.
Tomato, or Love-Apple	Lycopersicum esculentum	Solanaceæ.
Watercress	Sisymbrium nasturtium	Cruciferæ.
Wormwood	Artemisia (various)	Compositæ.

The preceding includes nearly every herb that is grown for kitchen use in our islands; and it will be unnecessary to do more than give this list.

There are two crops, with a notice of which we may conclude the list of field and garden products of the farm. They are of an entirely opposite character, and are only specially suited for certain soils and climates, so far as our islands are concerned. We refer to hops and flax.

Hops.—Of late years, the crop of English hops has been so uncertain, that the prices have ruled very high. Still this has not led to a very greatly-increased breadth of planting, for the crop is a very risky one; although, if well and safely got in, it is extremely valuable, and of ready sale. Its use is intimately connected with that of barley, in the form of malt; for it is chiefly employed as an ingredient in brewing beer, to give a bitter flavour, and to "keep" porter, stout, and ale. The great hop county of England is Kent; but it is grown in many other parts, and might be in many more, if the farmer would make a careful and patient trial. One objection to its introduction on to the farm, lies in the fact, that it must be a special crop, as it cannot be made to precede or succeed any other in the season. It also requires much trouble and attention in planting, growing, training, and picking; most of which operations, in respect to the hop, are different to all others pursued by the farmer on the field, although, in some respects, similar to kitchen garden operations. Again, no soil suits so well as the loamy one, of two or three feet resting on chalk, as is so common in Kent, and whose surface soil is exceedingly friable and porous. Good tillage and manuring are essential for obtaining a large crop.

The plant is either raised from seed, or from the previous year's plants; and is also propagated by cuttings and shoots—methods that are generally preferred to the sowing of seed for the purpose of raising a crop. Bedded-out plants are those that usually give the largest amount of produce.

The appearance of a hop plantation, in many respects, resembles that of one of grapes. The plants are placed on raised surfaces, in straight rows, these being distant about six feet from each other. The plants are set in holes filled with compost, or stable-dung, the holes being about two feet square, and one deep. As the plants grow they are trained on poles, which sustain the hop-vine. At certain periods suckers are removed, to afford plants for the succeeding season; but, in June, the earth is banked up over the roots. The intervening spaces between each row are well stirred up occasionally, so as to keep the soil open.

When the flower is fully ripe it is picked by hand; and this gives employment to a large number of persons, who flock from all parts of the kingdom, but especially Ireland, at the hop-picking season; and places that previously were a model of quietness and propriety, then assume an entirely different aspect. After being picked, the hop-flower is taken to a kiln to be dried; and this operation is carried on as quickly as possible, so that the flavour of the hop may not be injured. When dried they are ready for the brewer's use, and are sent to market in pockets.

The valuable portion of the hop is its *lupulin*, or bitter principle. Botanically the hop belongs to the Nettle order, or *Urticaceæ:* and its genus and species are *Humulus lupulus.* Its tincture and infusion are used in medicine; and hop-pillows have long been a favourite sedative remedy in domestic medicine.

Hops, as already stated, are a crop that is of the most uncertain character. Besides the risk of a bad season, blight, &c., the greatest enemy that the grower has to contend with, is the hop-fly, or *Aphis humuli*, a member of the *Aphides*, or plant-lice, one of which is illustrated in the annexed cut. It is the *Aphis* that infests rose trees.

Fig. 346.—Hop-fly.

Mr. Dallas remarks—"The cultivation of hops is notoriously an uncertain business, and this uncertainty is mainly caused by the occurrence, in some seasons, of vast numbers of these minute insects (the Hop-fly); whilst, in others, very few are to be seen. So great is the deficiency some-

times, that the amount of duty paid upon hops, in different years, has varied between £15,400 and £468,000, indicating, of course, a corresponding variation in the amount of the crops." This description, although now inaccurate in respect to the "duty," in consequence of the remission of it on hops, shows how great are the ravages of the insect. At that time the crop of hops was not reckoned according to the weight produced, but in respect to the probable amount of duty, which was quoted at various figures, according to the probable results of the season, and which it was intended to indicate.

Flax.—It is much to be regretted that, in our islands, the cultivation of flax has been so little attended to. In many parts, but especially in Ireland, large tracts of ground might be advantageously employed; and many attempts have been made to stimulate its production. At present, by far the largest proportion of flax used by the linen manufacturers of this country, is obtained from abroad. Belgium is especially famed as a flax-growing country. France, Russia, &c., stand next in importance. Some idea of the extent of flax production may be gathered from the fact, that our annual importation of it averages above 2,000,000 cwts., or 100,000 tons. About one-half of our supply is obtained from Russia and Prussia. Linseed, again, the seed of the flax plant, so much used for obtaining oil—and the refuse of that operation affording the chief oil-cake for the farm—is imported, annually, to the extent of upwards of 1,000,000 quarters.

Now, it would be exaggerating to say that all this importation is a loss to the country, because our manufactured goods are exported to pay for that import; but it does seem extraordinary that, in a land like ours, that possesses every possible variety of soil, flax should have so long been neglected as a regular crop, especially as a couple of bushels of seed are sufficient to sow an acre. Although not usually a rotation crop, it can be easily made so; and in Belgium it is rotated successively in six years, thus:—1, potatoes; 2, rye, with carrots; 3, flax; 4, rye; 5, turnips; 6, oats; the number indicating the successive years of rotation.

Flax forms, botanically, a separate order,

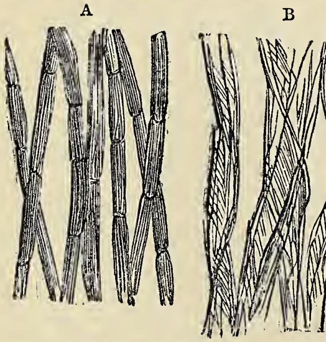


Fig. 347.—Fibres of Flax, A; Cotton, B.

known as *Linaceæ.* "It is a small family of plants, chiefly annual, with showy, fugitive flowers, characterised by the tenacious fibre of the inner bark. The most important species is the common flax, *Linum usitatissimum.*" The fibres of flax are peculiarly formed; and by way of comparing them with those of cotton, an illustration of each is given in the preceding cut; A showing flax, and B cotton fibres.

The general method of sowing, growing, and preparing flax for the manufacturer, has scarcely varied for ages, although it has been attempted to substitute the use of machinery in place of water-retting. But the latter method not injuring the fibre, is still followed by most growers, and preferred by the majority of manufacturers. For the following account of all the early processes, we are indebted to the late Mr. Barlow: it explains the method usually adopted; and, after the quotation, we shall add a few remarks gleaned from other authorities.

"The flax plant is an annual, requiring to be sown with the seed of the last year's produce, from the second week in March to the middle of April. It succeeds best in a free open loam, which is neither subject to too much wet nor drought: it is certain of producing a good crop on new ground, and will generally thrive on any soil which is proper for barley or oats. It remains on the ground till the end of July, or the middle of August, when it ripens, and is fit for pulling (unless it should be desirable to keep it for seed only); and may be succeeded by a crop of wheat or turnips, for which it is an excellent preparation. It may also be sown to advantage with clover-seed, which will then succeed it as an after-crop. Hemp is a much more rank and coarse plant than flax, growing from six to sixteen feet high, and is, more or less, common in all countries. It is, however, chiefly cultivated in the northern parts of Europe, whence it is largely imported into Great Britain. It thrives well in England; and English hemp, when properly manufactured, is found more compact, strong, and durable than that of Russia. It should be sown about the same time as flax, in a deep, rich, moist soil, on which account the Isle of Ely, and the fens of Lincolnshire, are particularly favourable to its growth. Like flax, when sufficiently ripe, it is not cut, but pulled up, root and all; on account of which both these plants leave the soil particularly clean.

"The first operation is to obtain the useful fibre from these plants, which is situated between the interior wood and exterior bark of each stalk, and has commonly been obtained by an aqueous decomposition, or by rotting away the wood and exterior bark by exposure to moisture, since the fibre itself (though, no doubt, somewhat injured by the process) has sufficient strength and durability to withstand it in a great measure. The process of rotting away the woody from the fibrous parts of the plant is one of extreme antiquity, it being noticed in the sacred writings, and having been used, not only in this country, but on the continent, from time immemorial; notwithstanding which, it has proved extremely detrimental to the health, not only of the inhabitants, but of the cattle of those countries in

which it is carried on, to a considerable degree, and is a system which, on this account, it would be desirable to abolish. It becomes the source of many pestilential diseases, among which, perhaps, the malaria so prevalent in the vicinity of Rome and Naples, may be numbered;* besides which, since flax and hemp ripen about the month of August, and require to be submitted to the process as soon as they are taken from the ground (at least before they are dry), the farmer's attention becomes necessary to them at a time which is most valuable, and can least be spared—namely, in the time of, or immediately antecedent to, his corn harvest.

"The operation of rotting, or, as it is most commonly called, *water-retting*, flax and hemp is one of considerable nicety and hazard to the cultivator, on which account it has, in all probability, proved a much greater barrier to the cultivation of these useful plants in our island, than the alleged exhaustion of soil, or any other cause; for its perfection, and the period when it should cease, depend on several fortuitous circumstances, which may dispose the woody matter of the stem to decompose with greater or less facility. Thus it will be influenced by the strength and vigour of the plant, the moisture or dryness of the season, the temperature of the air during the process, as well as the soil from which the plant was produced. If the operation be carried too far, not only the woody matter, but the fibres also will be destroyed or injured; and if not far enough, it has been generally thought that the flax will not dress; and thus, after a good crop has been produced, it may be much injured, if not spoiled, in the incipient stage of its manufacture."

Fig. 348.—The Flax Plant.

In the above cut, flax plants, in flower, and ready for pulling, are represented.

"The steeping or watering of flax is most commonly performed in artificial ponds or canals, excavated by the sides of rivers, and generally about forty feet long, six feet wide, and four deep—a sufficient size to admit the produce of an acre of land at once. Sluices are so disposed that the contained water can, at any time, be let off, and a fresh quantity of water, which should be soft, admitted. These canals should be exposed to the sun, which assists decomposition. The fresh-gathered flax being tied in bundles or handfuls, is carefully placed in these reservoirs, the upper bundles causing those which were first deposited to sink; and in this way each reservoir is filled, but not to such a degree as to force any part of the flax to touch the bottom; and when filled, the whole surface is covered with close hurdles or boards, and sufficiently loaded with stones to cause every part of the flax to be under the surface of the water. In this state it is left, and occasionally examined, to ascertain how far the process of decomposition is completed, which will generally be within a fortnight. The bundles of flax, which have, by this time, become very tender and difficult to handle, are now to be taken out on boards or trays, and removed to the nearest short grass or heath, where they are regularly disposed in rows to lose their moisture; and in which situation they receive an additional preparation from the evening dews, and occasional showers complete the decomposition, and, at the same time, wash away the slime and mucilage with which they are mixed. This last exposure is called dew-retting, and continues, according to the state of the atmosphere, for four or five weeks, or until the flax is as dry as it can be got, of a clear good colour, and all the woody matter that remains is perfectly brittle. The fibre will still retain most of its original tenacity if the operation has been carefully and skilfully conducted. It is then carried away like hay, on a fine dry day, and deposited in barns, being now ready for the next process, called *breaking* and *dressing*, which is the separation of what is commonly called the *boon*, or woody matter, from the *harle*, or useful fibres; and this may be effected in various ways. It is done in mills by machinery, and by hand; and in almost all cases is very effectually performed by a set of blunt iron [steel] teeth or breakers, fixed upon one piece of wood, and met by another similar set of teeth, fixed to a movable piece, which is worked by the one hand, while the flax, in handfuls, is introduced between these teeth, in various directions, with the other hand."

The hand-break is represented in the following cut: it is a block of wood, five or six feet in length, by ten or twelve inches in width, and is deeply grooved throughout its whole length, the edges of the grooves being sharp, and their depth an inch. On this another block is fastened at one end by hinges; and, by the handles at the other, it can be raised and lowered on the flax between both. The top block has longitu-

* We have preferred not to break the text of Mr. Barlow's remarks, but must add, that the malaria, above spoken of, arises from entirely different causes, that have not the most remote connection with flax processes.

dinal edges, which fit into the grooves of the lower; and by working the flax in the manner

Fig. 349.—Flax Breaker.

shown in the cut, the stalk is broken without injuring the fibres, which are thus separated from the woody matter.

"This breaks and knocks off the greater part of the wood in fragments; and the operation is completed by *scutching*, or beating the flax against a smooth post, called a scutching-post; and also beating it with an instrument called a hand-scutch, by which the few remaining fragments of woody matter, or boon, are taken away, and nothing but the long fibre remains, which is now to be hackled or drawn by the hand over a species of comb, having a great number of very sharp, long, and perpendicular

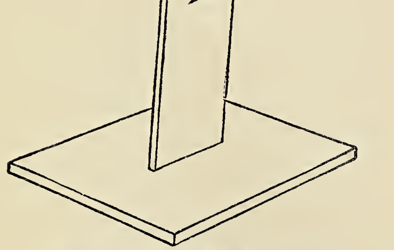


Fig. 350.—The Flax Scutcher.

steel points upon it, by which any remaining boon and the short fibres of tow are removed, and the long fibres which remain are regularly disposed, and ready to pass into the hands of the spinner."

Fig. 350 represents the flax-scutcher, A, and the scutching-post, or board, B, named in the preceding description. The flax is put into the notch of B, and beaten by A, the fibre being continually shifted by the left hand, to expose fresh surfaces or quantities to the scutcher.

Of course we have omitted all description of machines that might be, and are used, on the large scale, in thus preparing flax for the spinner, our only object having been to submit to the farmer sufficient of the usual processes adopted in the growing and preparation of flax, as may be pursued by labourers on the farm—as far, in fact, only as the grower of the flax need proceed to prepare the fibre for market. The machine for flax-breaking, &c., consists of "three fluted rollers, one of which is made to revolve by horse or water-power, and carries the other two round. The flax plants are placed between these cylinders whilst revolving, and the stalk is by this means completely broken without injuring the fibres. The scutching is accomplished by the same machine, by means of four arms projecting from a horizontal axle, arranged so as to strike the stalk in a slanting direction, until the bark and other useless parts of the plant are beaten away."

Mr. Scott Burn, after a lengthened sojourn in Belgium, visited the flax-growing districts, and remarks, that "the soil sought after by the Flemish farmer for his flax crop to come to the highest perfection, is that which is new, easily worked, strong, and fertile, neither too wet nor too dry. The finest flax is obtained in the deep soil of a clayey sand or loam. Rotations are carefully attended: the guiding principle by which they are arranged is, to keep the interval between two crops as long as possible." After giving the system of rotation as adopted in various parts of Flanders, he adds—"The preparation of the soil for the crop is a matter of the most anxious care with the Flemish farmer; it is deeply worked, carefully cleaned from weeds, and richly manured.

"As soon as the crop which it succeeds is off the ground, the soil is ploughed up, and the clods well broken by a roller. Later on in the season the land is again worked, so as to bring it to as firm a tilth as possible, the land being left in deep ridges. In spring, the land is again ploughed and well harrowed, the manure being liberally applied at this stage. This manure is composed of human excreta, urine, and rape or oil-cake dust. The land being thus finally prepared, the sowing is proceeded with; the period for this being generally from the end of March to the 10th of April. The seed is sown broadcast; and, as soon as it is in the land, is harrowed with a light harrow. Towards the twelfth or fifteenth day the weeding of the crop is begun. This is most carefully done; indeed, it is carried to a nicety which would in this country, where weeds are, unfortunately, not so dreaded as in Flanders, be considered altogether unnecessary."

We have thus considered all the chief crops

of the field, and such plants as will be of value in the kitchen garden, as an adjunct to the larger operations of the field. It is obviously impossible, in the comparatively brief limits of this work, that we could afford a full and a detailed account of everything that is connected with farm operations. It has been attempted, however, to take up the whole subject in a comprehensive point of view, making the applications of science to agriculture the basis of all that has been advanced.

It will be, of course, obvious that the differences of soil, temperature, climate, &c., that obtain in our own islands, must preclude the possibility of any general system of agriculture being described that, in its application, would produce equal results in each case. Indeed, having visited almost every part of our islands, and resided, for considerable periods, in many portions, we make full allowance for empiricism in farming. An agriculturist of the south of England, if transplanted to Yorkshire or Cumberland, still more to Scotland, would be almost sure to wreck his fortune in a few years, were he to carry on, in his new locality, the same system that he had practised in Kent, Sussex, Hampshire, or adjacent counties. It has been often said, that the salvation of Kent, in regard especially to corn crops, is the ruin of England. Through a great part of that county, the soil is so porous, with an immense depth of chalk subsoil, mostly intermingled, in layers, with flints, that nature has done to perfection, in respect to drainage, what man can never hope to aspire to. But, in many soils, especially north of Rugby, it requires all the benefit of extended experience of the country, careful watching of the weather, and, in fact, untiring diligence and perseverance. Yet, with all these accompaniments and qualifications, a storm may blast the labour of a year. At the time this is being written, our rain-gauge, a few miles out of London, shows a fall of upwards of two inches in twelve hours, and that at the end of July. This quantity is equal to a tenth of the fall, in Kent and Essex, for 365 days, or 730 times the period of rain-fall. Now, in those two counties such a fall will prove of the most beneficial character. It will swell the ears of corn; moisten the parched ground for the green crops; encourage the growth of the grass; and, having done all this good service, will quietly draw off into the river or sea, or evaporate, to produce fresh and refreshing showers. But, northwards, a few hours will bring distressing accounts of laid crops; hundreds, thousands, and, perhaps, tens of thousands of acres, under water; and stacks of hay, &c., carried by impetuous torrents down the streams of rivers. Hence the impossibility, in a work like the present, with the most extensive and varied knowledge, to suit it to the requirements of all classes of readers.

Nevertheless, there are certain broad general principles that may guide all our readers. In the earlier pages, after introductory remarks, we pointed out how the geological, chemical, physical, and botanical conditions of agriculture have universal application, wherever man or beast has to be fed. Now, a principle, to be general, must be capable of universal application; but, in its details, that application may be partial and local. It has been our endeavour, therefore, whilst explaining broad principles, to show, as far as possible, how such could be modified to suit individual cases.

At p. 378, *et seq.*, we have strongly urged the necessity of adopting chemical analysis, as far as possible, in *all* branches of agriculture. It is impossible to exaggerate the benefit that may thence arise to the farmer in the purchase or rental of land; in the selection of its soil to particular crops; in manuring; and other farm occupations. In fact, the whole of this section, subsequent to the pages devoted to instructions in chemical analysis, has simply consisted in a detailed application of chemistry as pointed out by analysis, not forgetting, of course, such conditions as already have been noticed. It cannot be too strongly impressed, at the same time, on the intelligent farmer, that, at a comparatively trifling expense, and by the exercise of patient intelligence, he may, in a very short time, make himself sufficiently proficient as to gain a general, and, indeed, particular, knowledge of the soil of his land, in a chemical point of view. A general merchant, or dealer, if he did not keep up an accurate account of the quality and quantity of his stock, would not only be unable to supply the wants of his customers, but would, eventually, find his name prominent in that portion of the public journals least to his credit—to wit, the bankruptcy gazette. Similarly, a farmer's stock does not simply consist of a certain number, in head, of cattle, sheep, poultry, pigs, stacks of wheat or hay, &c.; but his main stock is in his land: for, as we have been careful to point out, if *one* only of its needed constituents be absent, practically, all are absent.

In reference to the management of soils and manures, we have not hesitated to devote much space. It is a leading feature in modern farming—first, to discover what a crop requires; secondly, to examine the soil, to find any deficiency; and, lastly, having learned what the nature of that deficiency is, to supply it artificially by manures of all kinds. The nature, properties, relative values, &c., of all those in modern use, have been fully described at p. 386, *ante*, and in subsequent pages. Two different views have been maintained in respect to the relative value of manures; one contending that nitrogenous, and the other, that phosphatic, manures are the most advantageous to a soil. Common sense shows that either, or both, are required under certain circumstances; and hence a leaning to either view, in a partial or unphilosophical manner, has been avoided in treating on the subject.

We have not hesitated to devote much space to the consideration of what is commonly called the "sewage question." In the greater part of Europe, it is a matter that can scarcely be exceeded in importance, because it is so intimately connected with that of the supply of food for man and animals. *Theoretically*, the

sewage of any town *must*, necessarily, contain every matter essential to the growth of plants ; but, *practically*, the question arises—Can that sewage be utilised in such a manner as will be profitable to the farmer? From p. 395,' and through many subsequent pages, we have endeavoured, impartially, to state the whole subject in its most minute details. A recent report of her majesty's commissioners, appointed, not only to inquire into the subject, but to enter into the most minute experiments relating to it, has been largely used, for the purpose of presenting our readers with facts and data that can be relied on ; and we leave the question quite unprejudged, so far as the result of those experiments is recorded. Personally, we are under full conviction of the value of the sewage, judiciously applied and economically distributed —these two being essential conditions of its successful application ; but, at the same time, we have no hesitation in saying, that the undulating character of the surface of our islands is such, that but few places exist, throughout their whole extent, where the expense of the distribution of town sewage will not more than counterbalance its pecuniary value to the farmer ; consequently rendering artificial manures, guano, &c., far cheaper in practical use on the farm.

The subject of irrigation by water alone has been but briefly noticed ; and that of the reclamation of land omitted as a whole, because both are more connected with engineering than with chemistry, the application of which can only follow the efforts of the engineer or farmer. But these subjects, together with that of the sewage, affect the community otherwise than in an agricultural point of view. Sanitary questions, or those affecting the preservation of health, are not the least inferior to those that deal with the production of food : for of what use is food to a dying or dead man? Hence it was desirable to devote some space to the conjoint consideration of these subjects.

The mechanical operations of the farm, although, at first sight, apparently not related to chemistry, are really so in an eminent manner. By draining alone, on sound and extensive plans, can the full chemical action of air and moisture on soil and manures be effected, and the healthy growth of the plant ensured. Indeed, the absence of an efficient system of drainage has retarded the progress of agriculture, and the application of chemical principles in its exercise, more than any other cause. It is, therefore, impossible to urge too strongly on the notice of the farmer this condition of his success. For precisely the same reasons we have insisted on deep ploughing, and a high state of pulverisation of the soil, as essential to successful agriculture of *every* crop the farmer can grow in the field or the kitchen garden. Indeed, the superior fruitfulness of the latter is largely, perhaps chiefly, due to the regular breaking up of the soil which spade husbandry effects. The plough, at best, is a rough instrument compared to the spade ; and the difference of their action and effects on the soil is, that the plough turns over a large area, and the spade a small area, to produce crops generally productive of greater weight on the small than on the large area.

Thin sowing always, and transplanting when possible, have been insisted on, perhaps with a persistence that some may consider dogmatic. On this point we shall defend ourselves by saying, that we simply appeal to the impartial and comparative trial of the ordinary thick sowing and the thin sowing, and feel confident that the result will be greatly in favour of the latter. Our reasons have already been given at p. 427, *et seq.*

We have thought it desirable to offer some advice on the management of farm machines generally, and especially of the steam-engine, so that accidents may be avoided, and thorough with large efficiency be ensured. The comparatively recent introduction of steam machinery on the farm, has not allowed of the training of a body of men who would specially devote themselves to the study and proper care of such engines ; and the wages that the farmer can offer, would rarely tempt any but the idle or destitute of skilled men to tend his machinery, as the wages of a skilful millwright, steady at his work, per week, are about from £2 to £3 —a sum greater than the income of most small farmers. The remarks and advice that we have offered may, consequently, prove of value to those who, from narrow income, can only afford to put an ordinary labourer of good intelligence into the position we have spoken of, and may lead not only to the avoidance of failure, but to the prevention of serious consequences to property and life. Some useful contrivances have also been mentioned, that may save loss of time if kept on the farm, and also unnecessary pecuniary expenditure. "A stitch in time saves nine," is a motto as applicable to the farmer as to the tailor ; and many an accident has happened through a broken nut or shaft, or some other matter, that a little mechanical ingenuity, and proper tools at the homestead would have prevented.

Last in the list of subjects, those of the crops which the field and kitchen garden produce, were brought into notice. We have endeavoured to put all necessary details before our readers, whether as regards choice of soil, manure, species and varieties of plants, &c. Of course the two latter conditions, that of species and variety, are subjects of selection by the agriculturist, either for the field or kitchen garden. Generally, the species of plants grown on the farm in this country, for each plant, are exceedingly few ; whilst the varieties are very large. It was, therefore, deemed desirable to give extended information on the latter ; and hence the best varieties of corn crops, grasses, "roots," as the potato, mangold, &c., miscellaneous crops, kitchen garden produce, with those of many plants essential to the farmer, and not here named, have been given. As already indicated, such varieties increase yearly ; but as we cannot peep into the future of either the garden or field, we have been compelled to give the latest

information, subject to all further possible correction.

Of course, many matters of greater or less importance, in connection with agriculture, have necessarily been omitted, on account of the limits of space imposed on us. But sufficient has been said, at least, to indicate the road to improved culture, now so extensively adopted throughout our land. One point, not hitherto mentioned, may be insisted on: it is that of keeping a register of all the operations of the farm, whether of an ordinary or experimental nature, stating every circumstance that influenced any result attained. For example, a manure of a new kind, or in greater quantity, may have been applied to some portion of the land. Besides quantities, all the conditions of season, temperature, increase or decrease of crop, should be noted; for the keeping of such an account will afford a most useful book of comparison for guidance in future trials. Closely connected with this, is that of keeping a systematic account of all the pecuniary expenditure on the farm, and the amount in money it produces. This system of book-keeping is at the foundation of all success in manufactures and trade generally, as it enables a person to ascertain, exactly, the cost of what he produces, and, consequently, to control his profit or loss. It is but rarely adopted on the farm; but is just as essential there as in the merchant's counting-house.

In conclusion, we can only express the hope, that what has been here remarked, whether as regards principles, facts, experiments, theories or doctrines, may serve, at least, to keep the agricultural reader from errors of action, if not to lead him to the adoption of sound system and practice. Every branch of human art has, of late years, made enormous advances. Since the beginning of this century, the cotton and other textile manufactures, metallurgy, engineering, gas-making, telegraphy, and a host of other scientific applications, have grown with a vigour, and matured into a perfection, that are astonishing. But the oldest art of man, agriculture, has been the last to move. Thousands of past years have sanctioned modes of practice only now about being shaken off. Hitherto, the mass of the agricultural population has not been distinguished for that spirit of intelligent enterprise that has characterised almost every other class of workers. This, however, may be accounted for by the low state of education that has prevailed in most agricultural districts. A ramble through many of them reveals this lamentable state of things; but the perusal of the reports of government commissions, or those that have been given in the leading journals, far eclipses anything that could be imagined as evil in a formerly-existing state of things. In certain parts of the country, the harvesters are herded, without regard to age or sex, in places compared with which the barn is a paradise. Much has been said about the bothy system of Scotland, which is certainly a disgrace to civilisation; but within thirty miles of the metropolis, scarcely a better state of things exists at hay-making, reaping, and hop-picking. To accompany a lot of hay-makers, &c., conveyed by steam-vessel from the Irish ports to England, thence to trace their progress to various districts, but especially to the hop plantations of Kent and adjacent counties, is to learn a history that makes humanity shudder. We testify to that which, in all the above instances, we have personally witnessed.

On the other hand, whatever amount of vice may exist in the manufacturing districts, it has a counterbalance in a more diffused education, and a higher state of civilised feeling, arising from the stimulus of artificial wants, engendered by the associations of a large town and a great number of inhabitants; and this tends, at least externally, to a better state of things in appearance, if not in reality. The farm-labourer, on the contrary, has few artificial wants; and hence he naturally approximates more to the condition of the animal than of the man. But whatever deficiency there may have been in mental development, the physical has advanced, in agriculture, as it has retrograded in manufactures. Fully adhering to the old adage, that a mind cannot be sound except in a sound body, we can but regard the agricultural population as excellent soil for mental seed; and doubt not, that, improved by scientific teaching, trained by discriminating experience, it will at last bear fruit—some thirty, some sixty, some a hundredfold.

In the preceding pages (765, *et seq.*) lengthened remarks have been made on the utilisation of sewage on the farm by irrigation and filtration. Eminent authorities have been quoted, and their facts and figures given, in an impartial manner, showing the real or estimated value of those processes for the disposal of town refuse. Very recently, however, numerous processes have been invented and patented for precipitating both the matters in suspension and solution in sewage. They all profess not only to purify the sewage, but to afford a valuable manure for the use of the farmer. The author of this work has carefully investigated all these chemical processes, and has taken part in their trials. He regrets to state that, with one exception, the Native Guano, manufactured by the A B C process, all have been failures, and, in the case of the Native Guano, the prospects give little ground for encouragement in the future.

CHAPTER XIII.

SUGAR; SUGAR-REFINING; MALTING; BREWING; WINE-MAKING; DISTILLING; VINEGAR-MAKING; BREAD, ETC., ETC.

A STRANGER to chemical science would at once suppose, on reading the above heading, that a most incongruous arrangement had been made of matters utterly distinct from each other. The chemist, however, will at once perceive that the subjects to be dealt with have been arranged in precisely that order which his favourite science dictates.

For example, taking the term sugar in its generic sense, it includes the various forms of cane, grape, and milk sugar. The second heading is equally applicable to all three of these forms of sugar.

Our third heading, *malting*, is intimately connected with sugar, for the sole result of that operation is to convert the starch of the malt into saccharine matter, or sugar. In malt, grape sugar is the cause of the sweet taste of that form of the grain; and, as we shall eventually show, grape and cane sugar have not only the relation of similarity of taste, but further, that their chemical relations are of a still more intimate nature.

Brewing, again, depends on the conversion of the grape sugar of the malt of barley into alcohol, more familiarly known, in its dilute state, as spirits of wine, and still more so as the intoxicating principle of beer, ale, cider, perry, wines and spirituous liquors.

Proceeding a step further, we find that distilling is consequent on brewing, because the distiller first ferments, if from malt, the sugar that it contains, by an addition of yeast, which converts the sugar into alcohol; and then he separates the "spirit" by heat, and condenses its vapour in a manner to be hereafter explained.

The making of wines is analogous to the brewing of beer; with the exception, however, that the sugar of the grape, as in that fruit, requires no addition of fermenting matter to cause its conversion into alcohol or spirit. The fruit naturally contains that influencing substance; and, as soon as a certain period has elapsed after the pressing of the juice out of the grape, fermentation commences spontaneously at a proper temperature, and the sugar of the grape, or grape sugar, is thus converted into alcohol. The distiller avails himself of this to get brandy by distilling the wine alcohol off.

Vinegar-making is consequent on all the preceding. The sugar of the grape becomes converted into alcohol or strong spirit; but by exposure to the air, or such other means as we shall subsequently describe, that spirit is converted into vinegar, in which the acid part, or taste, is caused by the production of acetic acid. Vinegar made from ale, therefore (more properly called alegar), is produced by the conversion of the spirit and any sugar that may be present in precisely the same way—that is, by the action of the oxygen of the atmosphere, which, oxidising both present, converts them into acetic acid, that thus produces vinegar, or alegar, by its presence in the liquid.

Lastly, and most unlikely of all, the making of bread, is an exactly identical process with such as have been described. The wheaten flour used to make bread, consists of a certain proportion of starch, and a substance called gluten. By the addition of yeast, the starch undergoes fermentation, and is converted, if the process is carried far enough, into sugar, alcohol, and acetic acid; hence the offensive acid smell often perceived as escaping from the oven of the lower class of bakers. But all that the baker requires is, by the method of fermentation by yeast, to produce carbonic acid gas, so as to swell the gluten into small cells, which render the bread digestible. As soon as the dough is sufficiently raised, he stops the further progress of fermentation, and puts the dough into the oven; and by the heat of that arrangement, at the same time drives off both the causes and the effects of fermentation that he had previously engendered, leaving the dough only physically altered in its form, but with a small loss of its weight, owing to a certain portion having been expended and decomposed in producing the effects that have been described.

By this brief *résumé*, of what has to be described in much fuller detail, our readers will perceive that every one of the matters named at the head of this chapter, is intimately connected with the rest. In fact, they form one series of causes and effects of the most interesting character, and that cannot be properly discussed in their individual character alone.

One of the most interesting results of scientific research is found in the simplifying effect it has in relation to a series of connected causes and effects. There is a wonderful transition of the sublime to the ridiculous, if we say that the motion of all, and each, of the members of our planetary system is governed by the same law as that which rules the weighing of a pound of cheese, or any other commodity. Yet such is the case. In both instances the law of gravitation governs the result. In chemistry, again, are thousands of instances similar or analogous to the extremes just named. Who would suppose, for example, that the source of our gas-light, coal, should simultaneously produce the richest colours of every imaginable hue, now almost exclusively used for dyeing purposes; the ordinary smelling salts;

and also a substitute for the flavour and smell of bitter almond oil? Again, it is not only possible, but a matter of daily practice, that the most rancid and offensive cheese and butter can easily be made the source of the finest flavour for confectionery purposes, imitating to perfection the apple, pear, and pine-apple. But such is the fact; and we cannot therefore be surprised that sugar and starch should be capable of so many changes as to be the foundation of our most favourite drinks. and the basis of the most valued breadstuff of civilised and savage life.

From what has been said, it will be evident that sugar should, in its nature and manufacture, take the first place of consideration in this chapter; although, when we address ourselves to the description of malting, we shall have to take a step backward to the study of the nature of starch, from which, in a majority of cases, and always in malting, grape-sugar is derived.

SUGAR, ITS HISTORY, PREPARATION, REFINEMENT, Etc.

When the preparation of sugar as a condiment, or article of food, was first undertaken, it is impossible to say with any degree of certainty. Mr. Potter, in his *Practical Directions for the Culture of the Sugar-Cane, &c.* (published some years ago, and backed by the authority of Mr. Barlow, who quotes him), considers that—

"The Chinese appear to have been the first people who discovered the properties of the sugar-cane; and it is tolerably well ascertained, that the inhabitants of that country enjoyed its use some centuries before it was known or adopted in Europe. There is no mention made of it in the history of Ancient Egypt, Phœnicia, or Judea; and the Greek physicians are the first who have spoken of it under the name of Indian salt, which, from the sweet taste assigned to it by Dioscorides and Pliny, without doubt was the same material which we now denominate *sugar-candy*.

"Indian salt was brought to Greece and Rome from Arabia and India, within the Ganges; but it was not cultivated nor manufactured in those countries. The cane, at that time, grew only in the islands of the Indian Archipelago, in the kingdoms of Bengal, Siam, &c.; and the sugar that was produced from it passed, with perfumery and spices, and other merchandise, to the countries on this side of the Ganges. It found its way into Arabia in the thirteenth century, the period at which the merchants first began to visit India, and to traffic in the Indian articles of commerce. If the cane had been the produce of that part of Asia which lies between the Ganges and the Mediterranean Sea, or of Arabia or Africa, this plant, which grows so easily in all warm countries, and which reproduces itself without culture, would certainly not have escaped the observation of the different tribes who inhabited and roamed over every part of these countries.

"Marco Paulo, a noble Venetian, was the first European who visited the countries in which the cane actually grew. He found that Bengal produced spices, ginger, and sugar in great abundance; and, upon the whole, gave so favourable an account of the country, that the merchants who had formerly gone to Ormus, for the purpose of trafficking with the Indians, now directed their steps to Bengal itself.

"The precise period, after the voyage of Marco Paulo, at which sugar was first introduced into Egypt does not appear; we are only able to ascertain, that, at the end of the fourteenth century, the cultivation of the sugar-cane, and the manufacture of its juice, were practised generally throughout Arabia, Egypt, and several other parts of Africa; and the testimony of various travellers, particularly that of Giovanni Leoni, proves that, in the fourteenth century, an extensive trade in sugar was carried on in Arabia Felix, Nubia, Egypt, Morocco, and Ethiopia.

"In 1420, when the island of Madeira was discovered by the Regent of Portugal, he introduced the sugar-cane from Sicily. It was cultivated with success there, as well as in the Canaries; and, soon after, the sugar of these islands, particularly Madeira, was greatly preferred to that of any other country.

"The Portuguese began the cultivation of the cane in the island of St. Thomas, immediately on its discovery; and we are told, on the authority of a Portuguese pilot, that, in 1520, this colony had more than sixty manufactories. The rich inhabitants had 200 or 300 negroes employed in the plantations; and there were made on the island, 150,000 arobas, or 4,650,000 pounds of sugar.

"Soon after Columbus discovered the New World, one Pierre Etienne took the sugar-cane to Hispaniola, since called St. Domingo, or Hayti. A Catalonian, named Michel Ballestro, was the first who expressed juice from it; and Gonzales de Velosa was the first to concentrate this into sugar. * * * * The cultivation of the sugar-cane in St. Domingo certainly extended with great rapidity; and we are told that the cost of the magnificent palaces of Madrid and Toledo, erected in the reign of Charles V. of Spain, was entirely defrayed by the proceeds of the port duties on sugar imported from St. Domingo."

The first establishment of sugar plantations in continental North America, seems to have taken place in 1518; but doubt exists as regards the exact year, which has also been set down as 1580.

Gradually the growth of the sugar-cane spread throughout the West India islands. About 1641—'50, it was produced, of inferior quality, at Barbadoes; and sugar was first made by the English at St. Christopher, in 1643, and by the French at Guadeloupe, in 1657. When Jamaica was taken from the Spaniards it only contained three small sugar plantations. Eventually the growth of the cane, and the production of sugar in an edible form, extended in all directions, from the centres just indicated; and, at the

present time, it is a universal commodity of all hot climates, if favourable soil be present. Owing to the abolition of the slave-trade and slave labour in the British dominions, its production for some time decreased, as far as our colonies were concerned; and, at the present day, it is stated that free labour is far too expensive to be a profitable means of producing sugar in our islands. Better let the trade perish than that it should be a fruit of such an iniquitous system as once disgraced our name as a nation. Recent events show, however, that although nearly fifty years have elapsed since the liberation of the slaves in our West Indian islands, still much of the old leaven of malice between black and white exists, proving the inveterate and inexterminable power of prejudice, habit, or caste.

Whilst thus giving a brief outline of the history of cane sugar, we may add, that the ingenious Chinese were, according to the best historical account, the first to practise a systematic method of crystallising and partially refining sugar; and in this fact we find another evidence of the extraordinary advance they had made in every art when Western Europe was sunk in barbarism. Rumphius states, that their method was as follows:—"The expressed juice is received into large boilers, placed on brisk fires; as the juice evaporates, more is added till it becomes thick and red; then it is put into deep earthen vessels, which are taken to a warm place. The sugar at the surface forms crystals, which are united in white clusters, called cakes of sugar; and that which crystallises underneath is called muscovado. The sugar is clarified in large boilers with the whites of eggs; a little chicken fat is used in the operation; it is afterwards put into large earthen plates to crystallise. That which is obtained from cakes of sugar is very large, white, and hard, resembling crystal: it is called *male sugar;* that which is obtained from muscovado, the crystals of which are sweeter, and less hard and fine, is named *female sugar.*" It is evident from this that the Chinese pursued chemical practice, wittingly or unwittingly, on correct scientific principles. Indeed, until very recently, the process adopted in Europe varied only slightly in detail from that just described. It is believed that the Venetians introduced the art of sugar-refining into Europe in the fifteenth century; first imitating the Chinese method; subsequently, however, adopting the use of cones, and selling the manufactured product as loaf sugar.

Such is an account of what is known of the early production, manufacture, and methods of refining: we next turn to give some account of the sources.

In the first place, it must be noticed that, at least, three kinds of sugar are known, and these are divided into cane sugar, or *sucrose;* grape sugar, or *glucose;* and milk sugar, or *lactose.* Each of these is a compound of carbon, hydrogen, and oxygen, varying, however, in the proportions of each. Their sources and properties differ materially.

Cane sugar is typified by that produced from the sugar-cane; but it is also afforded by beetroot (a very common source on the continent), the date palm, the maple tree, the cocoa-nut, and Indian corn; and, doubtless, is obtainable from many other sources. It is the sweetest of all known forms of sugar, and is that universally employed in domestic life, in all countries, for sweetening, and other ordinary uses of sugar. It is readily crystallisable, although, by long-continued heat, the property is lost, and cane sugar, by constant boiling with water, may thus be converted into grape sugar. Yeast has precisely the same power, and thus cane sugar is largely employed, at the present day, in brewing, being converted into grape sugar by the action of yeast, at a temperature of about 80°, when alcohol and carbonic acid are formed.

Grape sugar is that kind which is typified by the sugar found in ripe grapes, honey, and in a disease of the human frame known as diabetes. As already stated, it is also produced in barley, by the process of malting; and is that condition of sugar for which the brewer, distiller, and vinegar-maker are indebted for the production of the articles of their manufacture. It may be procured artificially from cane sugar by fermentation, as just stated; and *lignin,* as found in linen rags, is readily convertible into this form of sugar. It is essentially the sugar of fruits; and many of our readers will have seen and tasted it, as incrusting some kinds of raisins, which owe their sweetness to its presence. Honey largely contains it.

Grape and cane sugar are thus distinguished. Cane sugar, on the addition of strong sulphuric acid to its solution as a syrup, gives up its water, and disengages its carbon as a black frothy mass; whilst a solution of grape sugar presents no such appearance under the same conditions. Potash, in the caustic state, produces no effect on a syrup of cane sugar if boiled with it; but with grape sugar a dark-brown colour is produced. Cane sugar gives no precipitate on heating with potash and sulphate of copper, whilst grape sugar does. Grape sugar, again, affords a black precipitate on boiling it with potash and the ternitrate of mercury; but cane sugar affords no precipitate under the same conditions.

Yeast, acting on grape sugar at a temperature of 70° to 80° Fah., causes fermentation, and the subsequent production of alcohol, or spirits, and carbonic acid gas; and the same result follows with the action of yeast on cane sugar, but it is first converted into grape sugar.

Milk sugar, although entirely apart, in a practical point of view, in respect to the subjects now under discussion, is of great interest, as connecting the vegetable and animal economy. It partakes mutually of the characters of cane and grape sugars. It can be crystallised like, in some respects, cane sugar; and with that substance affords a charred appearance on the addition of concentrated sulphuric acid. But, like grape sugar, it produces a brown colour on being boiled with caustic potash; whilst cane sugar presents no appearance of the kind under

similar circumstances. With sulphate of copper and potash it precipitates the suboxide of the metal, and affords a black precipitate with potash and the ternitrate of bismuth—results distinguishing it, again, from cane sugar. It is readily obtained from the milk of almost all mammalia.

Such are some of the leading points of difference, or resemblance, between the three conditions of sugar that are found in the vegetable and animal kingdoms. Practically, these are of little importance, because the processes of manufacture only belong to different forms of cane sugar. Grape sugar is produced without the agency of man by natural processes; and, in one sense, cane sugar may be placed in the same category. But the latter merely requires mechanical processes for its extraction and use; whilst grape sugar, equally natural with the preceding, undergoes, in the hands of man, a variety of changes that produce, as already shown, the drinks familiarly known as beers, wines, spirits, &c. Or, in plainer terms, cane sugar is chiefly valuable and available as a mechanical product; whilst grape sugar is only valuable in the results of the chemical changes to which it is subjected.

Having thus noticed some of the leading points of difference that subsist between the different forms of sugar, we proceed to those details that are of a more practical character.

The ordinary cane sugar of commerce is obtained from varieties of *Saccharum*, as the *S. officinarum*, *S. violaceum*, *S. sinense*, &c. The plant, as already stated, was doubtless a native of Southern Asia, although now never met with in a wild state. It belongs to the *Gramineæ*, or Grass order, and is chiefly cultivated for commercial purposes in India, the East and West India Islands, Mauritius, South America, in Brazil and China. The "sugar-cane" grows to a height of from six to twelve, and even fifteen feet, bearing a large panicle of soft hairy flowers. The success of its cultivation much depends on the nature of the soil; for, like all grass crops, it requires a new and moist soil to make it attain its greatest height. The usual mode of planting has been described as follows:—"The field is prepared by marking out the ground in rows three or four feet apart; and in these rows holes are dug from eight to twelve inches deep, with an interval of two feet between the holes. Where the ground is level, large spaces are left at certain intervals, for the facility of carting; but there are many situations on the sides of steep hills where no cart can be taken, and in such cases these spaces are not required, for mules are employed instead of carts." It is especially necessary, as with all other crops related to the Grass order, that weeds should be kept down as much as possible, and hence hoeing is an essential labour in tilling the sugar-cane. The following cut will give some idea of the appearance of the cane, its plantations, and the act of hoeing.

The cheapness of labour, especially in slave countries, permits of much time being devoted to hoeing; and there is little doubt that the labour so expended is rewarded by an increase of crop; but still much will depend on the

Fig. 351.—The Sugar-cane.

suitability of the soil. The temperature of hot countries rapidly evaporates all superficial moisture, and, consequently, "the soil, generally acknowledged to be most favourable for the growth of the cane, is one consisting of a mixture of clay and sand. Although the effects of rain on this soil are apparently soon over, its surface drying quickly, the lower or inner portion retains a degree of moisture even in the driest weather; and it has the advantage of seldom requiring trenches to be made, even in wet seasons. * * * * Black mould, of many varieties, is also favourable for the production of the cane; and the best that is found is that of Barbadoes, Antigua, and some other of the West India Islands; but there is a species of this mould in Jamaica little inferior to it, which abounds with limestone and flint, on a substratum of soapy marl. Black mould in clay is more common, but it is generally only in a very thin stratum, and the clay is tenacious and retentive of water. This last sort of land, consequently, requires great labour, both in ploughing and trenching, to render it profitable; but, properly pulverised and manured, it becomes extremely productive.* Canes will not flourish on mere sandy soil. To make them grow on it requires a great expenditure of manure, as well as frequent rains or large artificial irrigation."

The top part of the plant is that relied on for propagating the cane; a slip being planted in the earth, first cut from the top of a previous

* See remarks and experiments on this point, at p. 427, *ante*.

year's cane. The usual time for planting is between August and November; the rainy season then nourishing the young canes, and causing them to grow luxuriantly, and to form a shade to the roots, that prevents excessive evaporation and dryness when the hot weather comes on. Under certain circumstances of climate, an early period of planting becomes desirable, or beneficial; but this point is chiefly regulated by a kind of custom, in every particular island or district, that long experience has sanctioned.

When once a plantation has been well laid out on good soil, and all other circumstances being favourable, the canes will continue to produce yearly for a considerable period, without the necessity of replanting, and thus resembling, in this respect, other members of the grass tribe. But this depends on the quality of cane first planted, which, if inferior, may not last more than two or three seasons; but if of a superior kind may bear for twenty years.

But a sugar plantation is subject to many causes of injury; and particularly the attacks of small insects of various tribes, which seek the cane for the sake of its juice, and wound the exterior of it, to arrive at their coveted food. The effect on the canes and plantation generally, is technically known as the "blast"—a name fitly chosen; for so completely destructive may such attacks become, as to completely ruin an entire plantation in one season. A kind of grub of a moth is equally destructive with the preceding; and, from the attacks of myriads at a time, planters have been completely ruined.

When the canes are fully ripe, they are cut nearly close to the ground; and, after being tied up in bundles, are conveyed by hand, mules, or other means, to the mill, which consists of iron rollers or cylinders, placed near together, and, by passing the canes twice between them all, the juice is completely extracted, and is ready for subsequent operations, to which we shall presently more fully allude. The refuse of the cane, after the expression of the juice, and called trash, or megass, is used as a fuel for the various operations of boiling, and others requiring heat. As the canes contain a considerable amount of silica, they afford a beautiful slag of a glassy nature, somewhat like that which may be procured, under certain circumstances, by the combustion of wheat-straw, and the fusion of its silicious matter.

The juice, as extracted from the cane, contains several matters, as albumen, &c., which, left for a short time, would cause fermentation analogous to that which takes place in the expressed juice of the grape; and, eventually, the sugar would thus be converted into an acid liquor, in a similar manner to that which occurs in making vinegar from either wine or beer in temperate countries. To prevent this, it is at once conveyed to large vessels, called clarifiers, heated by a fire. Lime, or lime-water, is added to the juice; and this causes the coagulation of various substances with which the cane-juice was mixed at the time it was first expressed. As soon as these impurities are removed, the remaining liquor is evaporated, to remove, as much as possible, the watery portion, and to concentrate it; and this is carried to an extent sufficient to cause the sugar to assume a granular or grain-like appearance, on account of the formation of irregular crystals, on cooling. When sufficiently evaporated, as indicated by this granular appearance being produced on cooling a portion as a test, the liquor is transferred to coolers, and it is allowed to cool down slowly. By this means the sugar separates as a mass of crystals of a brown colour, mixed with a dark-brown liquid, called molasses, which will not crystallise. The crystals are separated from the molasses by putting the whole mass into large vessels having small holes at the bottom. Through these holes the molasses trickle gradually away into a vessel placed beneath to receive them; and when as much as possible of the molasses has been removed, the solid mass of sugar left becomes the coarse, moist, or brown sugar of commerce, variously known as "foots," muscovado, or raw sugar, &c. The operation of separating the molasses from the sugar, is carried on in a separate building, called the curing-house.

Before describing the method of sugar-refining, we may notice, in greater detail than has hitherto been done, some other sources than that of the sugar-cane.

In France and Central Europe generally, cane sugar is not used; the root of the beet being the source of sugar in those countries. The plant is familiarly known in England, as used for food of cattle, a dressing for salads, and occasionally as a pickle, of a deep red colour. The juice of the *Beta vulgaris*, of the botanical order *Goose-foot*, or *Chenopodiaceæ*, is that employed; and the details of its extraction, and first preparation, do not essentially differ from what has been stated in reference to the juice of cane sugar. One ton of good beetroot will afford about 100 pounds of raw sugar, and when refined as "loaf-sugar," it produces about fifty-five pounds of that article. It is now largely produced in England.

In the United States of North America, and Canada, another source of sugar is found, and very generally adopted in the latter country. The sugar-maple, *Acer saccharinum*, of the Maple order, or *Aceraceæ*, possesses a sweet sap, which is collected in spring by tapping the tree to the depth of about half an inch with an auger, and inserting a spout. Good sugar-maples will afford, on an average, about four pounds of this sweet juice. The sugar is removed from it by evaporation, by which the liquid is reduced to a syrup. This is clarified and crystallised, and gives a brown-coloured matter, resembling the brown cane sugar. All samples that we have tasted of maple sugar were very sweet, but had a slightly bitter or aromatic taste; but when used to sweeten coffee, could not be distinguished from raw cane sugar. It is largely used by emigrants in our North American colonies; and from the abundance of the maple there, is a cheap source of sugar for all kinds of domestic use; indeed, a supply of an unlimited extent might

be produced of maple sugar: but, practically, cane sugar, except at the places named, and which are generally inaccessible to regular commerce, is found to be cheaper and more economical in use. The mode of clarifying and crystallising maple sugar is similar to that adopted for cane sugar.

Some of the Palm order, or *Palmaceæ*, afford a sweet juice, from which sugar may be obtained. Thus, if the juice of the flowering branch of the cocoa-nut tree, *Cocos nucifera*, be collected by making an incision into the leaves, and the liquid be distilled, an intoxicating liquid, called arrack, will be afforded on fermentation and distillation. Vinegar may also be obtained from the same source, by leaving the juice exposed to the air, both products showing that grape sugar is present in the juice either naturally or by conversion of the cane into the grape sugar, which was explained at p. 470, *ante*, as occurring under certain favourable circumstances. The Palmyra palm, *Borassus flabelliformis*, possesses a kind of vinous sap, which, when fermented, produces an intoxicating drink, called Toddy. It is also boiled down, to a great extent, to produce a coarse kind of sugar, known as Jaggery, or palm sugar. The sweet fruit of the date palm, *Phœnix dactylifera*, so abundant and valuable as an article of food to the desert tribes of Northern Africa and the Sahara desert, is another instance of the possession of sugar amongst the Palm order.

The preceding—namely, the sugar-cane, beetroot, the maple, and the palm—are the four chief sources of sugar on the large scale. All the fruits of temperate and other climates contain grape sugar; but this is of no value for the ordinary purpose to which sugar is applied, being deficient both in sweetening and crystallisable qualities, and also far too expensive.

Sugar-Refining.—Sugar obtained from any of the preceding sources, is so mixed up with impurities, especially molasses, which cannot be separated by mere draining, that it is necessary to refine it; and for this purpose several methods have been devised.

"In the old process of sugar-refining, a copper boiler was charged with lime-water, mixed with a certain proportion of bullock's blood; to this mixture the sugar was added; it was suffered to stand a night to dissolve, and early in the morning a fire was lighted under the pan or boiler. When the liquor boiled, the albumen of the blood coagulated, and, entangling the mechanical impurities of the sugar, formed a scum which was constantly removed. The simmering was then continued till a sample, taken out by a spoon, appeared transparent; after which it was rapidly boiled down till of such a consistence as to draw into threads between the finger and thumb, some practical skill being required to ascertain the exact point at which the boiling should be stopped. At this point the fire was damped, and the syrup transferred to a vessel called a 'cooler,' where it was agitated with wooden oars till it granulated. In this granular state it was transferred to the moulds, to be then treated in a manner we shall afterwards more particularly describe."

At p. 470, *ante*, we pointed out that, by exposing cane sugar to a continuous high temperature, its character or qualities become changed. It turns brown and uncrystallisable, as may easily be illustrated by holding a piece of lump sugar in the flame of a candle or gas-lamp, when a reddish-brown colour is produced, vulgarly supposed to be the bullock's blood with which the sugar had been refined, but really arising from the change in the nature, &c., of the sugar by heat, as just described. Now, under the old method of heating the sugar in the copper vessel by a naked fire beneath it, all these results took place. The higher the temperature to which the sugar is exposed, the greater is the injury done to its economic value. But a high temperature was necessary under the old method; for as the sugar undergoing the application of heat is viscid, it does not readily carry the heat communicated to the bottom of the vessel to all parts of its contents, as water would do, because the great fluidity of water-particles promotes its rapid circulation in any vessel containing it, and subjected to heat.

This led to a most ingenious invention, by the Hon. Edward Howard, in 1819, by which heat is communicated to the syrup by means of steam, in a vessel from which air has been exhausted. Before describing this form of sugar-refiners, or boilers, we must, however, explain the principles of its action.

At the ordinary pressure of the atmosphere, say equal to thirty inches of mercury in the barometer, water will not boil and be converted into steam at a lower temperature than 212° of Fahrenheit's thermometer. But if we rise a few hundred or thousand feet in the air vertically, the boiling-point of water gradually becomes lower; and thus, on the top of some mountains in Europe, it may be made to boil at about 180° instead of 212°. The reason of this is, that as we rise vertically in the atmosphere, the pressure gradually becomes less. Thus, supposing that, at any specified time, the barometer at the foot of a mountain, and at the sea-level, indicated a pressure of thirty-one inches of mercury; another barometer, say at its top, of about 14,000 feet above the lower one, or the sea-level, would only indicate a pressure of about eighteen inches of mercury; and at that elevation water would boil many degrees less, in regard to the indication of the thermometer, than it would at the sea-level.

Again, if warm water be placed in a vessel, and this be put on to the plate of a good air-pump, and the receiver placed over it; on the air being completely withdrawn by the pump, the water, if of a temperature of a little less than 100°, or the heat of human blood nearly, will begin to boil, because *all* the atmospheric air has been withdrawn from its surface, and hence all pressure on that surface is at the same time removed. Lastly, the principle that we are explaining, of liquids evaporating at a lower temperature as the atmospheric pressure is withdrawn, may be very simply but instructively illustrated as follows:—Fit *accurately* into the neck of a clean Florence, or other glass flask, a sound cork, and,

removing it, nearly fill the flask with water. Apply the heat of a lamp till the water boils vigorously; and when nothing but steam and water remain in the vessel, cork it tightly, and at once remove it from the lamp. Now dip it into cold water, and the water in the flask will again begin to boil. The reason of this is, that by dipping the flask into cold water, the steam in the flask is condensed, and a vacuum like that produced by the air-pump is afforded. Thus all pressure is removed from the surface of the water in the flask, and, consequently, it will begin to boil again at a lower temperature, for reasons already explained.

All these illustrations serve to point out the principle of Mr. Howard's invention, now universally adopted for sugar-refining, whereby all the danger of injuring the syrup is entirely avoided; for only steam-heat is used, and no naked fires. The following cut illustrates a

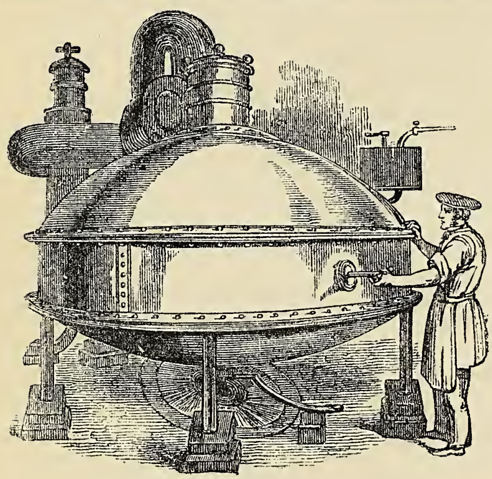


Fig. 352.—Sugar Vacuum Pan.

common form of the boiler, although it is varied according to different purposes, or the peculiar conditions in which it is to be employed.

"It consists of two hemispheres, somewhat flattened, and bolted together by flanges; it is made of copper, and is often of very large dimensions. The lower hemisphere is imbedded in a steam jacket, and has besides a coil of copper steam-pipe, which lines its interior, so as, therefore, to present a great heating surface, and to rapidly raise the temperature of the liquor let into the hemisphere. Attached to the pan, at its upper part, is a pipe of communication with a cylindrical vessel resembling the condensing apparatus of a low-pressure steam-engine, into which a sub-divided stream of cold water is continually passing, so as to condense the vapour arising from air constantly pumped out of the pan by means of an annexed air-pump, which, as in the steam-engine, keeps at a vacuum in the pan, and removes the water of condensation. The proper quantity of saccharine solution* is let into the pan by an adjoining measuring vessel, which empties its contents into the vacuum pan by the pressure of the external atmosphere. There are also several accessories to the vacuum pan—namely, a thermometer, a barometric gauge, and a proof-stick, which is a clever contrivance, enabling the attendant to take samples of the liquor in the pan without admitting air.

"At the lowest part of the under hemisphere of the vacuum pan is a pipe with a valve or cock, through which the sugar solution, when sufficiently boiled, is allowed to escape into the heater.

"Under these circumstances, then, the purified and decolourised syrup is reduced by evaporation to such a consistency, that it begins to granulate—that is, a sample taken out of the vacuum pan by means of the proof-stick, and placed between the finger and thumb, feels somewhat gritty, in consequence of the formation of small crystallised grains. When this is the case, air is allowed to enter the vacuum pan, and its contents are quickly drawn off into a vessel placed underneath for their reception, which is heated by a steam jacket. [This vessel is called the *heater*, and is represented in the following cut.]

Fig. 353.—Sugar Heater.

"Here the granulating syrup is agitated till it has acquired the peculiar condition or consistency which fits it for pouring into moulds, which are conical vessels made of earthenware or of glazed iron, or of copper, with a small aperture at the apex. These vessels are placed with the bases upwards [see following cut, which represents these vessels, and the mode of filling them], and the hole at the apex being stopped, they are filled with the granular sugar, which now concretes or *sets*, and may be represented as a mass of granularly crystalline sugar, the pores of which are filled with more or less pure syrup. Considerable practical tact is required to ascertain exactly the fit condition of the semi-fluid saccharine mass for introduction into the moulds: if too liquid, the loaf cannot properly solidify; if too concrete, it becomes what is technically termed *syrup-bound;* that is,

* Decolourised by methods presently to be described.

it does not allow the syrup to trickle from it when the stoppers are removed from the apices of the moulds—an operation which is conducted

Fig. 354.—Sugar Moulds.

in a warm atmosphere, and upon the perfection of which the character and appearance of the loaf mainly depend. It is in these conical moulds that the curious operations of claying and liquoring are performed; that is, the syrup is allowed to filter through the loaf, by placing a mixture of sugar and water upon its base, the watery parts of which dissolve away the residuary soluble matters as they pass, and dribble out at the apex into a vessel placed to receive them. In this way the colour of the loaf and its texture are improved; the former by the removal of certain soluble matters, the latter by the deposition of sugar from the percolating syrup."

We have been unwilling to disturb the continuity of the preceding quotation, from a paper read by the late Dr. Brande before the Royal Institution, at which place he formerly held a professorship, and was also master of the Mint; but must now add, that before the syrup is introduced into the vacuum pan, it undergoes different processes. First, the raw sugar is dissolved in water, to which lime-water is added. The lime removes many impurities, and the liquid is then run into a filtering vessel, which retains all solid matter of brown or black colour thrown down by the lime. The filtering vessel consists of cloth tubes, about three inches in diameter; and, having passed through this, the liquid comes out of a brighter colour.

But still a yellow or brownish tint prevails, that would utterly unfit the liquid to produce white sugar. This colour, however, is readily removed by filtering the liquid through a bed of animal charcoal. This is made by calcining bones of various kinds until they are perfectly black. Thus a fine porous charcoal is afforded; and being made into beds, the brown liquid sugar is filtered through, when it comes out perfectly free from colour, and as clear as water. In this condition it is transferred to the vacuum pan, already described and illustrated by Fig. 352, *ante*.

The syrup which passes from the apices of the mould forms the *treacle* of the shops; and when the whole of it is removed, and the moulds have become nearly dry, the surface at the base of each is scraped off, as represented in the following cut.

Fig. 355.

The next operation is to remove the sugar from the moulds, which is done by giving the latter a smart blow on the side; the loaf of sugar will then tumble out. The pointed end is then turned at a lathe, as represented in the following cut, and any discoloured surface removed. The loaves are then wrapped in

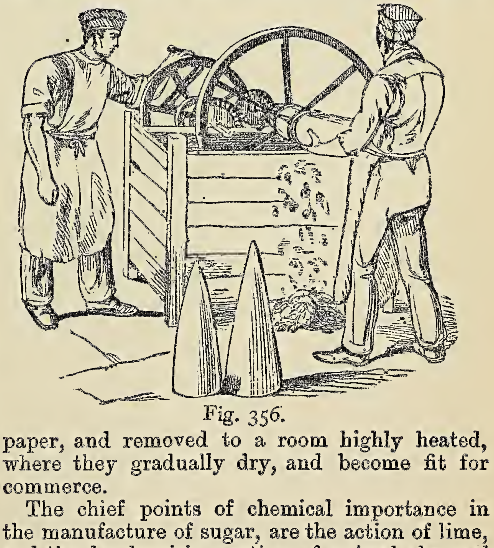


Fig. 356.

paper, and removed to a room highly heated, where they gradually dry, and become fit for commerce.

The chief points of chemical importance in the manufacture of sugar, are the action of lime, and the decolourising action of animal charcoal on the syrup before concentration. Several plans have been proposed to substitute other

substances for the animal charcoal, which is expensive, although that objection is partly removed in consequence of the charcoal that is used being readily bought by the farmer; for containing, as it does, much phosphate of lime, it becomes a valuable manure for the land.

One of the most ingenious of these proposed methods, is that discovered, some years ago, by Dr. Scoffern, but which has been limitedly employed, and now, we believe, is entirely disused. His invention is based on the fact, that a solution of acetate of lead will completely remove from syrup of raw sugar all the colouring matter and many impurities. But acetate, and all other soluble salts of lead, are deadly poisons; and if more than the exact quantity of a solution of lead were added to the syrup, every loaf of white sugar might become a storehouse for a deadly poison, as insidious as it would be fatal.

But Dr. Scoffern proposed to remove the least possible trace of lead by means of sulphurous acid—a compound of two equivalents of oxygen with one of sulphur, and familiarly known as producing the powerful suffocating fumes that are afforded when brimstone or sulphur are ignited. His general method was as follows:—Raw sugar is dissolved in water, aided by steam-heat, and the proper quantity of acetate of lead in solution is to be added. The contents of the vessel holding this are to be well agitated, filtered, and through the filtered liquor a stream of sulphurous acid is to be passed. This acid at once unites with lead, producing an insoluble sulphite of that metal, and so the lead is removed from the solution. The syrup is afterwards filtered and tested with sulphuretted hydrogen, to find whether all the lead has been abstracted; and this test is exceedingly delicate in its action, forming a black sulphide of the metal if only a minute quantity be present. On the addition of a little chalk, and filtration if necessary, the syrup is perfectly clarified, and ready for boiling down in the vacuum pan previously described.

A great prejudice, however, was created against the use of this invention; and we regret that the ingenious inventor has not reaped the just reward for so clever a method of dealing with the impurities of sugar, and which would at once have been a saving of much time and expense.

Numerous improvements have been effected in machinery applied to the production of sugar from the cane, that we cannot spare space to detail; and as they are of a purely mechanical nature, would not interest our readers. In many recent exhibitions some fine specimens were shown in connection with the requirements of the planter and sugar producer.

Our preceding remarks have been almost entirely devoted to the consideration of cane sugar. Grape sugar being intimately connected with the processes of malting, brewing, distilling, and wine-making, will be best enlarged on in connection with those subjects, as its fermentation alone gives rise to them all. The sugar of milk has no application in the arts, except as a vehicle for homœopathic medicines, in which it is largely employed. It differs from the sugar of grapes in being incapable of vinous fermentation by the addition of yeast.

It is peculiar to sugar of milk that its sweet taste is very slight. As sugar of grapes is found in the chyle and blood, and corresponds, in its composition and properties, very nearly with sugar of milk, the latter is therefore to be derived from the sugar of grapes, and also from the amylaceous or starchy substances of our nutriment, which are transformed into sugar during the process of digestion.

The uses of cane or ordinary sugar are too numerous to be here detailed. As a condiment in sweetening beverages, it is, perhaps, chiefly employed. It is also much used for preserving both fruit and meat. Sugar, whilst being digested, enriches the gastric juice with a substance that assists in dissolving the aliments; for the sugar, on coming in contact with the saliva, has been partly converted into lactic acid, which acts upon the nutritive portion of the food in the same manner as the hydrochloric acid of the gastric juice.

On the supposed injurious effects of sugar on the teeth, an able continental writer observes—"Since the composition of milk has been recognised, the sugar ought to have been acquitted of the bad repute which adhered to it for many centuries. A slander always leaves something behind; and even to the present time, the popular belief that sugar injures the teeth, is as widely spread as, on the counter-testimony of both experience and science, the opposite doctrine ought to be; for the teeth of the negroes in the West Indian colonies are of a bright white; and that which is thus proved by a whole community remarkable for the abundance of sugar consumed by them, the example of many individuals nearer home amply confirms. Phosphate of lime is the chief constituent of the bones and teeth, but not before adult age; and an increase of the phosphate of lime is the essential character of the development of the bones of children. Lactic acid dissolves the phosphate of lime of the food; and as sugar indirectly supports this solution, it facilitates the conveyance of lime to the teeth. To this it must not be objected that sugar causes pain in a hollow tooth. Like sugar, a thousand other substances irritate the nerve; but who seriously believes that that is necessarily injurious to the healthy which gives pain to the diseased? The prohibition of sugar to children, therefore, is indefensible. Sugar is not dangerous to the teeth; but, on the contrary, assists in providing them with lime; it is useful to the stomach, if it do not, by being taken in excess, produce too great a quantity of lactic acid."

MALTING.

That man has sought out many inventions, is a fact which all mankind tacitly admits; but of all inventions that have been made, the one involving the production of intoxicating drinks is that which has made the most universal progress in the world, savage or civilised.

Perhaps it was an unfortunate thing for humanity when, amongst all other inventions, that of wine was discovered. Far be it from us to advocate that total or pledged abstinence which is simply an indication of the absence of moral control. Nature, or rather its Maker, has placed before man, not only the "good" and the "bad," but the power of selecting either as the rule of existence. The sin or perversion of "drink," amounting, at times, to a mania, is simply indicative of the imperfection of humanity, and a test of the moral power of the mind of the man who uses a certain gift prudently, or as an abuse. The habit of "drinking" is so universal, that no careful thinker can come to any other conclusion than that man has a certain instinct to use certain stimulants. But the excess in that use does not necessarily forbid the article of drink: it simply points out that the perversity of humanity insists on converting that which should be a blessing into a curse.

Every philosopher—that is, the man who takes nature as it is—must see that, in the normal state of humanity, little or no liquid is required as a beverage. The greater part of our food, of all kinds, is constituted of water: meat, vegetables, fruit, &c., are all storehouses of that invaluable fluid. In the quiet country walk, in sporting, and other engagements in the open air, at times the brook may supply all the loss that an excess of perspiration carries off in the form of water from the system. Occasionally the loss is enormous. Experimentally we tried the matter several years ago, and, during a lecture to a large audience, standing not far from a hydro-electric steam-boiler, we had lost $2\frac{1}{2}$ lbs. in weight, in less than an hour and a-half, on a hot July evening. Such a result is constantly occurring in India, and other hot climates; and hence it is absolutely necessary that such a waste of the fluid part of the animal should be at once replaced, otherwise injury both to organ and function must ensue.

We feel, in this matter, that a most delicate ground has to be trod on. Our own opinion, although not followed in personal practice, and, therefore, giving the greater weight to the opinion, is, that an entire abstinence from the use of all intoxicating liquors is that most consonant with health and happiness. But in dealing with such a question, man must be taken as he *is*, and not as he *should be*. At the present day the tendency is to fearful overwork of mind and body. Literally, in all civilised countries men live too fast. No time is left for eating, sleeping, resting, or calm thinking; hence "drinking," which stimulates the vital action for the moment, although it shortens the duration of life, is had recourse to.

Under such circumstances it cannot be a matter of surprise that brewing, wine-making, distilling, and rectifying, are occupations of great extent in all civilised countries. Even the wildest tribes have discovered the art of preparing intoxicating liquors by means of fermentation. Perhaps the most abominable of the kind is that prepared by the natives of the South Sea and Society Islands, from a species of pepper, *Piper methysticum*. The savages first chew the root of the plant, and then project the saliva into a large bowl, where it ferments, and produces an intoxicant from the kava root. The Tartars, again, by fermenting mare's milk, produce a spirituous liquor, known as *koumis;* and so, in each part of the world, a taste, naturally existing, or artificially stimulated, is discovered.

In our own islands, beer, brewed from corn, is certainly the "natural," or national beverage. Debarred from the production of wine by the peculiarities of climate, we have recourse to malt and barley, for the production of a substitute. Hence the practice of converting barley into malt, as the basis of porter, ale, stout, and various British spirits.

Malting essentially consists in converting the starch of the barley into sugar. The starch of a seed is an insoluble substance, which, by chemical action, may be converted into a soluble one, in the form of sugar. Now this starch of a seed is intended to form the first food of the growing plant; and to do this, it is, by the act of germination, first converted into sugar. This, being soluble, is fed on by the growing plant, the chief part of it consisting of the *plumule*, or *acrospire*, which grows upward from the seed, and the *radicle*, or *root*, which grows downwards, and, in ordinary growing plants, occupies the soil, as the stem, leaves, fruit, &c., are seen in the air above the surface of the ground.

Barley is the chief form of corn used in malting. It is the most profitable for being converted into malt; yet a great variety of starch and sugar substances are available for the use of the brewer and distiller. In fact, perhaps the purest kind of spirit is afforded by pea-shells. According to an eminent authority, "the barley most proper and profitable for malting is the rath, or early ripe, which ripens two or three weeks before other kinds, and is that which growers ought to select, not only for its being so early ripe, but also on account of its making malt superior to any other, by reason of the thinness of its skin, being more plump and heavier, and on account of the sweetness of its nature. Perhaps, amongst the varieties of barley, the Chevalier is most esteemed for malting purposes, and is that most grown for the use of the maltster."

According to the authority just quoted, night dews are invaluable in mellowing barley intended for malting; but we cannot advise our farming readers how to secure such an advantage, considering the peculiarly changeable nature of our climate. It is almost needless to add, that when the duty on malt was charged by the quarter, the purchase of the heaviest samples of barley for malting was effected; and great care was taken that it was not damp, otherwise germination, which it is the object of the maltster to produce, may have taken the precedence of his operations, and would, therefore, render his processes valueless and fruitless.

We quote, from an eminent brewer (Mr.

Levesque), in his *Art of Brewing and Fermenting*, the following observations on the character of the best barley for malting :—

"Barley, when in high condition, has but little smell, which is sweet and pleasant. Barley, after being threshed out, and lying damp, or exposed, will soon lose its freshness, smell strong and disagreeable, which must, of course, depreciate its value. Large quantities of barley come coastwise to the London market; great care is required, and, no doubt, is taken, to ship it in the best order; but contrary winds will prolong the voyage, and therefore spoil the cargo by overheating, so as to render it unfit for the purpose of malting. In order to ascertain the condition of a cargo, samples are to be drawn out of the middle of a bulk. When barley has been overheated in the stack, the germ end of the grain is turned of a blackish-red colour, which denotes that the germ is killed; and, in order to distinguish the one from the other, take the skin off the germ end of the corn so discoloured, when it will appear shrivelled, or dried up; but, in an uninjured state, the germ is full; and if the skin be carefully taken off, it will be yellow in colour, and similar [in appearance we presume] to butter. Barley, of the best quality, is uniform in size, and bright in colour; but if of two colours, this denotes it to be a mixture; or it may be hedge-grown, which is objectionable for malting, as it will not work even. The maltster should be careful in avoiding mixed barley—old and new—as such will never grow evenly, nor work well together; the size, shape, colour, and hardness may be so similar, that it will be difficult to perceive the difference. The maltster, in examining the germ, will perceive a visible difference; the new being pale, and the old of a darker yellow, which sufficiently proves that there is a mixture, either of old and new, or of unequal qualities. The missed corns, of course, will not vegetate; and they therefore reduce the value of the barley, according to the number missed. * * * * In good seasons, the maltster's judgment will seldom fail; but when crops are unfavourable, he requires the test: therefore, if the least doubt occur, let him by no means omit putting a sample of the doubtful grain, loose in a bag, into the cistern, there to steep with other barley, and from thence to the couch, taking its chance in the bag with the other, always keeping it underneath the surface, until its vegetative powers are sufficiently displayed for his purpose. Barley produced from light land is thin-skinned, and of a pale yellow; * * * so the barley from clayey land is thicker-skinned, of a deeper yellow, and altogether of a coarser quality. The very best thin-skinned barley, in some seasons, will weigh fifty-six pounds, avoirdupois, per bushel; and whilst the maltster is looking after quality, he should also be mindful of the weight, remembering always that the lightest barley pays most duty; therefore he should not malt any below fifty-six pounds per bushel, but from necessity. Barley ought not to be cut before it is quite ripe, because, previously, it has not obtained all the natural qualities required for malting. Barley, from not having had sufficient warmth for ripening, not having sweated in the mow, may yet sweat in the bulk, in a bin, or it may have a warming on the kiln, at a summer heat [70°, and upwards], previously to being steeped."

The preceding quotation is replete with excellent advice to the maltster, who will do wisely to attend to all the remarks offered. It is well known that a great variety exists in the character of malt liquors; and a connoisseur can readily detect the peculiar flavour that attends the production of each brewer. Hence the high character of many firms, whose names will at once suggest themselves, in connection with London porter, stout, and ale-brewing; and the production of bitter ale at Burton, and other well-known places.

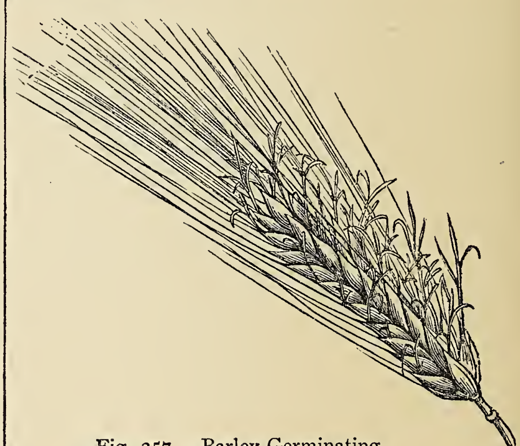


Fig. 357.—Barley Germinating.

It will be now quite understood, therefore, that the maltster has, for his purpose, to cause the sprouting or germination of the barley, for the object of converting its starch into sugar. In the above cut, an ear of common barley is illustrated, in which each corn is supposed to be growing. This germination may be very prettily illustrated by placing a few ears of any kind of corn in a tumbler filled with moistened sand, their stems, an inch or two long, resting in the latter. If placed on a mantelpiece, beneath which is a fire, or in warm weather, each grain will germinate, and cast out leaves, their starch being converted into sugar, and this latter affording food for each little growing plant.

The practical process of making malt may be explained, now that we have described the chemical principle on which the operation is founded. We may first note, however, that although barley is preferred, universally, for making malt, still it is not, necessarily, the only seed capable of such conversion: for wheat, oats, peas, buck-wheat, beans, Indian corn, potatoes, and, indeed, every plant, or fruit of a plant, that contains sufficient starch, may be made available. But we confine the following remarks entirely to the malting of barley.

The place in which malting is carried on is termed a "malt-house." The essential parts of the "house" are the floor, the steeping cistern, and the kiln, besides storehouses or lofts for holding the barley before and after it has been converted into malt. The floor may be, advantageously, the ground floor of the building. The cistern, for steeping, is placed at one end of the floor, and the kiln at the other, with the store-place for the malt overhead: for by such an arrangement each operation may be made successive in regard to position. A floor formed of Roman cement is a good one for the maltster, because being, if properly made, impervious to external moisture, it prevents any interfering cause from operating on the processes carried on. It is extremely essential that the walls, floor, &c., should be kept free from everything that might injure the malt; and hence repeated lime-washing is desirable. It must be remembered that malting is a process with which many circumstances, apparently of a trivial nature, interfere; and not only may the malt itself be affected by neglect of such consideration, but the beer brewed from it may be seriously injured, or rendered completely unfit to drink.

The barley is first steeped in the cistern, which is filled with water, technically called "liquor," to a height of a few inches above that of the barley, resting on its bottom; and the grain is left there as long as it swells. The liquor is then drawn off, and the grain is left to drain until no water will further pass off. The time of steeping is reckoned by tides, each being of twelve hours' duration. A longer time is required for steeping in cold than warm weather; the time averaging from forty to seventy hours, but varying with the quality of the grain, temperature, and other causes.

The grain thus steeped is then removed to the malting-floor, forming a bed or *couch*, as it is technically termed, of about fifteen inches deep. Here moisture, and the oxidating action of the air, cause germination to commence. The grain gradually becomes heated, and throws off carbonic acid gas, evidencing that chemical changes are progressing in it. The root and acrospire both begin to form: technically the production of the root is called spritting; but the sprit should not appear whilst the grain is on the couch. "If the grain is suffered to sprit in the couch it will never come even afterwards, as the sprit corns will attract more than their due share of moisture; which moving and turning in due time, will retard and cause every corn to sprit very nearly at the same time, that otherwise would not have spritted, to the amount of one-tenth, more or less, until several days after the rest; therefore, at the time the forward corns are mellow, the latter will be in a waxy state, which is one cause of hard or steely malt. Herein lies the principal art of malting; and the maltster, who is aware of it, must be attentive and industrious to perform it well."

When the grain has been sufficiently long (at least twenty-six hours) in the couch, it is turned into the bed, the extent of which depends on the temperature, but which, in area, exceeds that of the couch. It is spread out here thinner than in the couch, and stirred. Here the spritting or growth of the root goes on; and, at the end of about twelve hours, the root is developed. Great care is taken not to let the root obtain too great a length, because the substance of the grain would be exhausted at the expense of the acrospire, which, in the meantime, is also growing. By thus thinning out the barley on the floor, its temperature is lessened, and the process of germination becomes manageable. If increased warmth be required, this is easily attained by spreading the grain in thicker masses.

A test of the progress of satisfactory malting is seen by the length of the acrospire, which should not be allowed to advance more than to the extent of two-thirds of the length of the grain, according to the authority already quoted, who states, that as "the acrospire is the substance and flavour of the malt," if "it be suffered to proceed beyond these limits, two-thirds, the more will the substance be exhausted, and the flavour changed; if suffered to protrude, either by the neglect or fancy of the maltster, this acrospire is so extremely tender and delicate, that it is difficult to dry it without scorching, which injures the flavour; and, in proportion to the protrusion of the acrospire, so is the malt made hollow and light, and so much has it lost in weight, and, consequently, in substance and fine flavour." When this part of the process becomes complete, the substance of the grain has become entirely changed. Instead of the seed being firm, as in barley, it becomes crumbling and mealy, being readily pulverised, or reduced to powder by the fingers, on the external skin being removed.

The next step is to stop all further germination, and dry the malt, which is effected by throwing it into a kiln. The temperature at which the malt is dried influences its colour, and the heat varies from 90° upwards; hence the production of pale malt, amber, and brown malt, besides another kind roasted black, which last gives the deep colour of porter; whilst the lighter coloured varieties yield ales of different but light tints, compared to those of porter and stout.

Much must, doubtless, depend on the kiln-drying for the flavour of the malt, or rather of that of the beer brewed from it. Towards the end of the kiln operation for producing high-coloured malt, a process called "blowing" is adopted. This is effected by putting over it the flame of burning faggots or billets of dry wood. By this process the greater portion of the sugar of the grain is destroyed, being converted into a form of *caramel;* but this has the advantage of affording the peculiar flavour and colour in brewing porter and stout, already alluded to.

In respect to the flavour of malt, a competent authority remarks as follows:—"A great deal is said by the party for watering on the subject of their being able to make their malt of a superior flavour, by sprinkling [that is, whilst the grain

is on the floor] ; but the question of a superior flavour, when applied to pale or common malt, resolves itself into this simple fact—that malt which is worked in the most pure, clean, and natural manner, will be the most free from all adventitious and improper flavour. While pale malt is worked on the floors, all that can be done is not to give, but to guard it from any peculiar flavour. On the kiln the case is widely different ; there, just in proportion as the fire is urged, slowly or rapidly, less or more of flavour will be given to the malt : it is in this way that all malt expressly intended for the brewing of porter has its peculiar flavour and colour given to it ; but the flavour of ale, generally speaking, is derived from a different source. This latter arises from the union of a peculiar oil of a greenish colour, naturally abounding in hops, with a portion of the unfermented wort, and the mucilage and alcohol of the fermented parts : these judiciously blended together in a due proportion, give to ale its agreeable taste ; but the palate being an arbitrary organ, and differing widely in different places, no established rule can be laid down for adjusting the flavour of ale. In some places the sweet taste of malt is required to be pretty full in the mouth, by leaving a larger proportion of the unfermented wort ; while in others it is required to be almost entirely dissipated by a more complete fermentation ; and between these a variety of flavours may be easily imagined." The author continues by remarking, that a common cause of injury to the malt, and, consequently, to the beer, arises from the intermingling of mouldy or decayed grains, that communicate their offensive flavour.

BREWING.

The art of brewing, in the largest signification of the term, would include the production, by fermentation, of all liquors used as beverages, from any substance containing or affording grape sugar (see *ante*, p. 470) ; but, for our purpose, we shall confine all remarks to that branch in which corn, converted into malt, is chiefly used, with the addition of sugar, as now largely practised, and allowed by act of parliament.

London, of course, as regards quantity of beer production, stands first in respect to brewing ; although the pale ale of Burton-on-Trent may approximate nearly to the amount of beer produced in the metropolis. Indeed, some years have elapsed since one of the leading firms in Burton have had their business restricted, not by want of demand, but by the comparative difficulty of transporting their produce by railway. This, however, has been overcome by the erection of enormous storehouses at the goods termini of some of the northern railways running to London, and adjacent to the metropolis. We must not forget to notice, also, the large production of some Edinburgh, Glasgow, and Dublin firms, all of whom come into powerful competition with the London brewers, whether in respect to quality, quantity, or price.

It is impossible to convey any idea of the extent of a trade such as that of brewing, otherwise than by referring to the almost universal use, in our islands, of a beverage that may be considered national in its character. Not that our country is the only or chief beer-drinking one of the world ; for many parts of Germany not only vie with, but exceed us in that habit ; and our American cousins are by no means behind us. Still, London porter, and Burton pale ale, have acquired a reputation that is world-wide amongst civilisation. Indeed, if certain accounts are to be trusted, the savages of Africa and the South Sea Islands have learned to appreciate the refreshing character of "malt-wine."

Ale and porter brewing have greatly benefited by the application of chemical science ; and not only so, other branches of pure science have equally, almost, in their application, contributed to the improvement, in quality and quantity, of the ale and porter brewed in the metropolis. According to Mr. Barlow, the first porter brewer in London who erected a steam-engine for economy of power in the brewhouse, and the substitution of mechanical arrangements for the labour of horses, "was Mr. Goodwynne ; and it was the first engine erected in London by the celebrated James Watt. Another was soon after put up by the celebrated brewer, Mr. Whitbread, at his establishment in Chiswell Street, where many improvements were introduced. Indeed, it is commonly asserted, that the steam-engine was first erected on these premises, which is, however, a mistake. The writer of this article [Mr. Barlow] has been assured by Mr. Goodwynne, that when Mr. Watt proposed to Mr. Whitbread to erect a steam-engine on his premises, he decidedly refused ; and that Watt subsequently applied to him [Mr. Goodwynne] ; that he agreed to make the trial, and that this was the first steam-engine which Watt erected in London. Whitbread's was, however, for a long time, one of the most scientifically arranged brewing establishments : " and we may add, as supplementary to Mr. Barlow's observations, that it still retains that character.

The "economy of manufacture" (to use a somewhat hackneyed phrase) is admirably carried out in the metropolitan and leading provincial breweries of the kingdom. Every appliance that art and science can suggest has been adopted, not only to save expense, but also to hasten and perfect the processes carried on. The great brewing establishments of the metropolis are held by persons possessing large capital, and equally large credit, which they neither want nor ask. A considerable proportion of the retail establishments, known as taverns and public-houses, are held by them on lease, or freehold, and hence a ready market for the disposal of their produce is always at hand. As a rule, the business is one understood as of "ready money." Each establishment has its *employés*, in and out of doors, occupied in a manner that, whilst one class produces the beer on the best principles, in respect to drinking and keeping, the other class superintends its distribution, and either keeps up or increases the

trade. The "cask stock" of a large brewery alone is an item of almost fabulous pecuniary amount; and this is taken at definite periods. In cases constantly occurring, an energetic man of business, deficient or short of capital, can obtain large or small loans from his brewer, at the current low rate of interest, security being given in such a form as may be safest for the brewer who advances the capital. In more than one instance in London, brewers are also partners in, or owners of, large banking establishments; and hence the situation of the trade, in every possible respect, is one to be envied by any man engaged in commerce.

It must be remembered, however, that whatever external advantages the large brewer possesses, there are certain counterbalances that must not only be taken into account in calculating probable profit, but that necessarily make the business one of considerable risk; and this latter arises from a variety of causes. A bad harvest may not only produce barley and hops of inferior quality, but, even thus deteriorated, such articles will necessarily, from the comparative scarcity so caused, command a high price relatively to that ruling in other seasons. Now, to attempt to raise the price of ale or porter, as sold retail, would be about as successful in result as an attempt to build a bridge to the moon, or to tunnel the Atlantic. A national revolution—in respect to drink—would at once ensue, which would either keep things at the present price, or largely diminish consumption. Again, brewing can only be profitably pursued on a large scale; hence the large brewers have always an immense amount of capital lying "dead," or unavailable, in the brewery, its plant, &c.; besides which, it is involved in purchasing the malt and hops, that do, or should, form the basis of all malt liquors.

But the art of brewing itself is one of considerable risk, and requires the greatest precautions in each stage of the process. Although proceeding on definite chemical principles, their application is only partly understood; or, at all events, if understood, the manner of its use is attended with numerous difficulties, in respect to temperature, the time of year, season, &c., &c. In brewing, a little leaveneth the whole; hence a small quantity of inferior malt may seriously injure a large "brewing;" that is, one at which considerable quantities of beer are produced at one operation.

The brewing trade, therefore, is not one of profit unalloyed with risk or difficulty. On the contrary, to be successfully carried on, it requires great experience, judgment, and capital; and hence arises the fact, that the great brewers in the metropolis, such as Barclay's, Whitbread's, Combe's, Truman Hanbury's, Reid's, and others, are but few in number; although each concern is of vast magnitude in respect to the area of its works, or customers' houses, and the amount of plant in use at each establishment. Some of these cover a surface to be measured by acres in extent, independent of storehouses for malt and beer, in other places than the brewery. In the same category are to be placed such firms as Bass, Allsop, and others, of Burton, &c., whose names are familiar as household words for household beverages.

We have already, under the preceding heading, entered into a full description of the methods of malting, and the conditions that must be observed in producing malt for the brewer's use. In respect to sugar, which is now also very largely consumed, under certain fiscal restrictions, we may refer our readers generally to p. 469, *ante*, and subsequent pages, for all the leading facts connected with its production, chemical characters, &c. In regard to hops, most of our readers will know that they are largely produced in Kent, and adjacent, with other counties in England, besides large quantities imported from abroad; and that they impart a bitter principle, which gives flavour to, and keeps beer.* The irregularity of the price of hops, owing to a variety of causes that influence the production of this tender plant, and its flower, introduces a highly distracting element into the brewer's calculation of profit and loss. In one year they may be abundant, and of excellent kind; in the next they may be nearly all destroyed by insects or vermin, and the weather. But hops are an article that the brewer cannot do without. No other material affords the rich bitter that they give; and hence have them he must, at any cost, for his brewing operations. Of all the kinds grown in this country, the Farnham are most esteemed, and command the highest price. Kent and Sussex, conjointly, produce about two-thirds of the entire amount of hops grown in England and Wales; and the "Canterbury grape" is largely cultivated in those districts.

Great care is required in preparing the hops for the brewer, who generally chooses them, as regards colour, to suit that of the class of beer he intends brewing. As ripe hops have the darkest colour, they are the best for porter brewing. In respect to the flavour they communicate to the beer, Mr. Levesque says—"The brewer must, in a great measure, be guided by his customers' palates. Bitterness is often complained of as being disagreeable, which may be owing to two causes; one of which is from ill-flavoured hops; the other, from long boiling, when the aromatic properties, which give the pleasant gusto, are dissipated into a disagreeable rankness; therefore let the brewer be particular in his selection. Hop lightly in the copper, and preserve the remainder for a period of storing or racking when in a mild state, which should not be drunk until the liquor begins to bite the hop; then the liquor will be effervescing, and fine flavoured."

But the effect that hop produces in the avour of beer, will depend largely on the amount of sugar that is left by incomplete fermentation of the wort. Hence the great difference between the bitter and sweet beers brewed in different parts of the kingdom, or in the same places, remarkably illustrated in the Burton sweet and bitter ales, as well as in those brewed in the metropolis, Glasgow, Edinburgh, &c.

* For account of the growth, &c., of hops, see *ante*, p. 461.

In respect to the water employed by the brewer, much difference of opinion, and as much error, have existed. At one time, it was supposed that the superiority of London beers of all kinds arose from the use of the water of the Thames. Now for this there is not the least foundation in fact; for the majority of the London brewers use water drawn from artesian wells, run into the chalk, which forms the bottom of the "London basin," geologically speaking. They thus draw up water that, having fallen in the form of rain over a wide extent of country, percolates through the surface soil, and at last collects in one immense reservoir, several hundred feet below the ground, and, consequently, below the bed of the Thames, the water of which has no connection whatever with that of the reservoir just alluded to, or of the water employed thence by the brewers. Indeed, so far from Thames water being, on an average, fit for brewing—at all events, between Vauxhall and Greenwich, within which limits all the large breweries are situated—it is more than probable, that an attempt at its use would result in the most serious consequences to the brewer. Some years ago its condition was abominable, although it is now materially improved by the main-drainage system; whilst the actual supply of Thames water, as afforded to manufactories and households by the companies south of the Thames, is drawn from Thames Ditton, beyond the reach of the tidal stream.

There is no doubt, however, that the presence of a certain quantity of lime, in the form of chalk, is valuable for the brewer, and improves the quality of water for his purpose. Why this should be the case has been never satisfactorily explained, although the fact is undoubted. The dyer discovers precisely the same thing, especially in dyeing certain shades of black, which are much deeper, and of fuller body, when produced, with the same expenditure of material, in water containing lime, compared with soft water. Salt is also necessary.

Apart from the apparent desirability of the presence of a portion of lime, there can be no doubt, that the purer and clearer the water is, the better will it answer the brewer's purpose. Hence the great value of artesian well water, which, from its circumstance of position, must have filtered, naturally, through beds of sand, &c., several hundred feet in thickness; and which is stored, till wanted, in situations to which no access can be had for vegetable and animal impurity. Some of the surface-well waters of the metropolis are so charged with impurity, that, in hot weather, they will, after having been drawn a few days, give off a most offensive odour, arising from the decomposition of animal and vegetable matter. One well with which we are acquainted, and that is situated in the centre of the city of London, is on the site of an old churchyard. For many years it was sought after for its "delicious," refreshing taste; but if exposed in the manner just indicated, the stench of decomposing animal matter it afforded was disgusting beyond measure.

The water companies of the metropolis are now compelled to filter the water they supply. This is generally done by forming reservoirs, in pairs. Into one of these, the water, from its source, and in an impure state, is admitted; and, by gravitation, it gradually filters into the other reservoir, through a gravel and sand bed, at the base of both, or rather forming the bottom of the two. By such means all mechanical impurity is separated; but the organic, or vegetable and animal, remain dissolved. It has been recently discovered, however, that if water, loaded with both inorganic or mineral, and organic, or vegetable and animal matter, be filtered through layers of animal charcoal, both sources of impurity are diminished, the organic being almost entirely removed.

The softest of any town water-supply in the kingdom, is that brought to Glasgow, from Loch Katrine; and it is so pure, in respect to organic and inorganic constituents, as to rank, of all natural waters, nearest to distilled water in purity. But we have not been able to ascertain that any advantage has thereby resulted to the Glasgow brewers from such purity, in its substitution for the Clyde water that had been previously employed. That city being situated on a large bed of rock, prevents the sinking of such wells as are universal in the breweries of the metropolis. Glasgow and Edinburgh, in fact, are placed over the "old" rock, geologically speaking; such as the carboniferous limestone, sandstone, &c.; whilst London is situated far above any rock, and at the top of the newest kind of tertiary strata. Hence, together with the basin-like form of its subjacent strata, is it that wells, affording an abundant supply, all the year round, of beautiful water for brewing, can be readily sunk and maintained.

We have thus noticed the chief materials of the brewer—namely, malt and sugar, hops and water; and next may make some remarks on the plant of the brewhouse, or those utensils that are essential to its operations. But before doing so, a few remarks on some other matters may be of interest.

All fermented liquors, before use, should, as far as possible, be kept at an even temperature; hence the care that is adopted in storing wines and beer. An extensive cellarage is, therefore, of the utmost importance to the brewer, and it should be underground, because the changes of temperature, winter and summer, are slight. The most biting frost in our islands never penetrates more than a few inches below the surface of the soil; and at a depth of a few feet, a constant temperature of from 45° to 48° is maintained during the whole year. It hence follows, that the lower a cellar can be made in ground, and the more completely all access of external air is prevented, the more even will be the temperature throughout the year. Of course, every care is required to drain the cellar well; for the influx of surface or other water would be, not only inconvenient, but harmful to the interest of the brewer.

In most breweries, immense tanks, called liquor-backs, are placed at the highest portion of the premises. Into these backs, "liquor"—

that is, water—is pumped constantly by a steam-engine; and, by means of pipes led to all parts of the building, an abundant supply for any and every purpose is ensured. It is also common to put into the water pieces of chalk, limestone, &c., that gradually, although in small quantities, become dissolved, and afford lime to the water—a method adopted for reasons just explained, when we discussed the water-supply of the London breweries.

Various parts of the brewery, in an extensive concern, are devoted to special purposes; as, for example, the store-rooms for malt, sugar, hops, &c. There are also vat and other rooms, that, with their contents, and the operations carried on in them, will be described as we proceed. All of them are kept as clean as possible, and free from damp, when that would be harmful. In some of the London breweries, such rooms, the engine-house, &c., are matters of great interest to visitors, from their extent and complete fitness for the objects to which they are devoted. Generally speaking, a large brewhouse is a model of perfection in the adoption of every contrivance or precaution that can in any way promote the thorough efficiency of all operations carried on within it.

Amongst the brewing utensils, or plant, as it is generally termed, the following are essential:—

The "copper" is of high importance, because in it the wort and hops are boiled together. It is made of copper; and, in some establishments, these vessels are of enormous size. The method of heating is by a fire placed beneath the boiler, and not by steam, which is now so much adopted in other manufactures; for the brewer wishes to get his liquors boiled as quickly as possible, and, at the same time, does not neglect economy of fuel.

The mash-tun is that vessel in which the crushed malt is steeped in hot water, to produce wort. Its size, of course, must depend on the extent of the operations of the brewery. It has within it, at the bottom, what is called a false bottom, through which the wort can pass, but which, at the same time, prevents the passage of the grains of malt. Between the false and real bottom are pipes and stopcocks, through which the wort can be drawn off.

The underback and hop-back are two other vessels of large size, that, in the course of brewing, receive the wort at stages to be hereafter mentioned.

Means are required for cooling the wort; and these are "coolers." The plans vary in different breweries; but generally these consist of extensive vessels, of a few inches in depth, into which the hot liquor is pumped. Abundance of air is allowed access by openings in the walls of the brewhouse, so as to cool the wort down rapidly after boiling. Refrigerators are also employed to expedite the process; and many different plans of the kind have been invented.

The gyle-tun is the vessel in which fermentation of the wort is carried on. It is either open at the top, to allow of the escape of the carbonic acid generated during the operation, or closed; but, in that case, fitted with a safety-valve, to allow of the escape of the gas, which would otherwise burst the vessel.

Besides the preceding, cleansing casks, stillions, settling backs, vats, pumps, and many other contrivances, of minor size, are needed to facilitate or carry out various operations. In many establishments the cooper's department is of great extent, for thousands of barrels, in the course of the year, require repair. Besides this, there are also arrangements for cleansing returned beer-barrels, by steam or hot water; for none of them can be employed a second time without being scrupulously cleansed, otherwise the new beer would soon spoil, and turn acid. Hence it is usually the practice to employ the casks in which the beer is sent out only when they have been fresh scalded; and thus one cause of flat beer is avoided. All our readers well know that beer, with the best "head," put into a dirty vessel, or one apparently but not really clean, instantly becomes flat, stale, and, for man, unprofitable.

Throughout the brewery, cleanliness of every surface that the beer has to touch, in any stage of brewing, is absolutely essential; and its neglect is sure to recoil on the brewer, to the damage of his pocket and reputation. The brewery is liable to many causes of injury, but especially the formation of fungus. It is this substance that rapidly forms on the outside of all vessels holding malt liquors; and may also be seen covering the exterior of wine-bottles that have been long kept in the cellar. As far as the wine is concerned, such can rarely do harm, because it is securely corked in glass bottles that are impervious to moisture. But the tuns, vats, casks, &c., of the brewer are differently circumstanced. Every contact with beer causes a small quantity to be absorbed by the wood they are constructed of; and hence, if such surfaces are not completely cleansed at each operation in the brewhouse, as well as with the casks that are used to send out the beer, the latter is sure to suffer injury. It is very likely that neglect of this kind causes beer so frequently to turn bad in summer weather; a new fermentation being set up, that causes the production of minute fungi in the beer in the casks, and is a prominent and constantly operative cause of diarrhœa.

Abundant use of lime in the brewhouse is of great advantage, as it is an opponent of all kinds of putrefactive, fermentative, and acid-producing agents. It is an excellent remedy for what is technically termed the *fox*, and the general effects we have described just now, on scientific principles. It also prevents the creaming of worts, in which we have detected the production of minute fungi by the naked eye and the microscope. It is astonishing how rapidly this fungus spreads when once it has set in, on either living or dead vegetable matter. Some years ago we were consulted, by a large tobacco manufacturing firm, as to the cause of a large quantity of one kind of tobacco they had in stock becoming perfectly unsaleable. On applying the microscope, the cause was at once discovered. The

greater portion of the shreds were covered with fungus ; and, on putting some good tobacco into contact with the bad, it also became covered in the same manner, turned acid, and was spoilt. In fact, fungus growth is very analogous to such diseases as affect man and the lower animals, and which are contagious, such as small-pox, fevers, &c. ; a diseased or fungus-covered part speedily spreading its maleficent influence in every direction.

Brewing Operations.

Having thus disposed of the material and utensils of the brewhouse, we next proceed to trace the malt from its being crushed until the beer from which it is made is ready for sale to the customer.

Practical brewing resolves itself into the following processes, pursued in the order indicated : viz.—

1. Mashing.
2. Boiling and hopping.
3. Cooling.
4. Fermentation.

Mashing.—This operation is intended to extract the sugar, &c., of the malt, and to dissolve it in hot water, to make what is technically known as *wort.*

The malt is not used in the state of grain, in which condition it arrives at the brewhouse. It is first crushed by rollers driven by a steam-engine, as represented in the following cut.

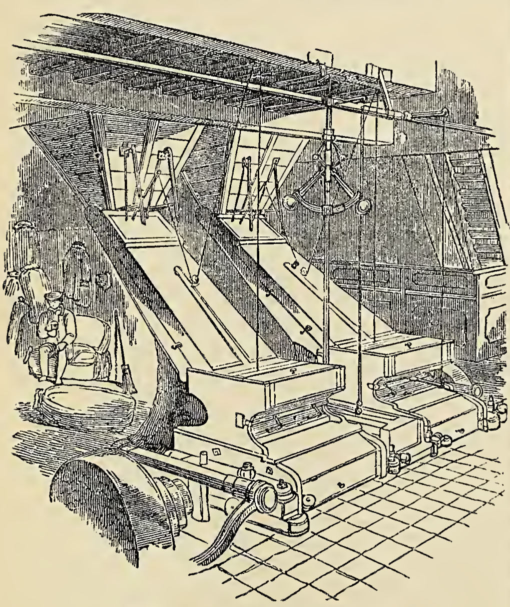


Fig. 358.—Malt Crushing,

The fineness of the meal produced is regulated according to the quality or character of the malt.

Rollers are generally preferred for the purpose, because of the little waste they cause. But some use revolving stones, contrived in a manner similar to the mill used for converting wheat into flour for the purpose of the baker. At the time of grinding, the various coloured malts can be ground together, in such proportion as may be desired in respect to the colour of the ale or beer afterwards to be produced. And here we may remark, that although we have hitherto named but three varieties—viz., pale, amber, and brown—yet the brewer recognises six, each of which requires a temperature differing by 5° Fah. for each kind. Besides these, is also patent malt, that is so prepared as to be used as a substitute for the brown and amber. The distinctions which the brewer makes in respect to the colour of the malt, are—pale or white, pale or turned, low amber, high amber, low brown, and high brown. The patent malt is now chiefly used for porter brewing.

In mashing, the mash-tun is either first filled with water, and the malt then let into it, or the water is driven through the malt. The temperature of the water must, of course, vary, as already stated, with the quality or character of the malt ; but one equal to about 150°, or a little less, may be taken as an average for malt as first put into the mash-tun. When the first-made wort is run off into the underback (the vessel intended to receive it), water of a higher temperature is let on to the malt left in the mash-tun, to more effectually remove the saccharine matter ; and the process is, according to the strength of beer required, repeated even four times. The grains have by that time lost all sugar available by the brewer, and are only fit for food for cows, the dairyman being an eager purchaser of them.

The malt in the liquor (water) of the mash-tun is kept well stirred up, either by oars or by a revolving machine ; and great care is taken that it shall not form little balls, which it has a great tendency to do. These balls cause a great waste of malt, because the inner part does not become exposed to the action of the liquor, and hence the saccharine matter is not extracted. They also injure the wort, by a tendency to produce acidity. Technically, the malt in the mash-tun is called " goods."

Numerous precautions are requisite, that we cannot here detail ; and, indeed, a knowledge of such characterises not only the practical brewer, but also his value in the brewhouse. In each establishment, modifications of a general system produce beer, by which the article sold by any brewer makes it characteristic of the "house" or firm that supplies it to the retailer. Indeed, such modifications form the chief secrets of the trade. Our unpractical readers will at once realise the results by tasting the ales and porters brewed by different firms, from the Burton bitter beer to the sweet Scotch and other similar ales, containing much saccharine matter.

The length of time required for a complete first mash is not more than one hour for large mashings ; and in smaller a less time only will be requisite. The wort is then let off into the underback through a tap, the false bottom of the mash-tun preventing, to a large extent, the

grains of malt accompanying the wort into the back.*

The brewer judges of the quality of the wort by the appearance of the head or froth, which should be silvery white, with a delicate cream on its surface; and this quality greatly depends on the accurate adjustment of the temperature of the mash-tun. Its strength will necessarily depend on the quantity of malt employed in reference to that of the liquor, or water. The first mash, in which it is usual to force up the liquor through the malt, affords, of course, the strongest wort, and is, therefore, that which must be employed in after-processes for making the strongest beer. The second and third, each in diminishing ratio, afford a weaker wort; and, of course, the use of these, separate from, or combined with those of the first mash, must be determined by the class of ale or porter brewed by the "house." It would be impossible to go into all the varied details that occur in respect to the quality of malt and liquor used for so great a variety of beers that are now manufactured. First, we notice that the value of the wort is denoted by its "gravity"—that is, the quantity of saccharine matter it contains—because on the quantity of that will depend the alcohol produced by fermentation, and the greater or less sweet flavour, according to the amount of sugar, and the extent to which fermentation is carried, as we shall subsequently have to notice. We here, therefore, content ourselves with noticing, that a quarter of good malt, weighing forty-four pounds per bushel—and, consequently, weighing, per quarter, 352 pounds—will yield two barrels of strong ale, of a gravity of forty pounds per barrel, for which four barrels of liquor, or water, are required in all. The first mash will receive, of this liquor, two barrels and two firkins; the second mash, a little over three firkins; and the third about the same quantity; whilst the fourth mashing will require two and a-half barrels extra to mash for returns. In all, therefore, six barrels and a-half of liquor, or water, are needed. With this quantity of malt twelve pounds of hops are supposed to be used.

In place of successive mashing, as above described, another method, called fly-mashing, or sparging, is adopted. It is that of letting in at the top of the mash-tun more liquor or water as the strong wort is being withdrawn at the bottom of the tun, into the underback. A cover is dropped into the mash-tun, over the malt already in, and from which the wort is extracted. The water is allowed to drop on this cover, which swims on the top of the wort, and breaks the force of the liquor running in to the tun. The wort is, of course, of greater specific gravity than the liquor that is thus run in, and so the latter keeps above the strong wort. This plan is substituted for the second and third mashings, previously described.

2. *Boiling.*—The next step is to boil the wort with the hops; and for this purpose it is pumped from the underbacks into the copper. These vessels are of great size; and are one of the curiosities of the brewhouse to the eye of a stranger. The length of time required for complete boiling varies; but one hour is considered sufficient for the wort of the first mashing; whilst the second and third may be boiled from one and a-half to two hours. The quantity of hops required will, of course, vary essentially with the gravity of the wort, and the extent of bitterness required in the beer. And either the whole of the hops is added at the boiling, or the greater portion is reserved for addition during the racking off of the beer at a subsequent stage of the brewing process.

Mr. Levesque remarks—and with his observations, on scientific grounds alone, we fully concur—"In respect to obtaining the fine flavour of the hop, long boiling is totally at variance with that desirable object; consequently, short, quick boiling is favourable to that purpose. It is impossible to boil without dissipation [of the aroma of the hop], to a certain extent.

"It may be objected by practitioners of minor experience, who are unacquainted with the principles and the chemical operations of brewing, that the liquor will not 'keep' without long boiling the wort with the hops; which is a mistaken idea, and extremely fallacious. The preservative quality of all malt liquor is resident in the soundness and purity of the extract drawn from the malt in the mash-tun, by the judicious application of the mashing-heats, in which alone the brewer can expect to find the principles of preservative quality; and the smallest degree of acidity, in this stage of the operation, can never be extinguished. It may be neutralised by a chemical application for a time; but no boiling will ever restore a wort unsound before going into the copper: therefore, the greatest care and nicety is required in obtaining a true knowledge of the fundamental principles of the art of brewing." Another judicious observation, from the same source, is—"If the richness of the worts require an alteration in the bitter, increase the quantity of hops, by putting them into the vat or cask, where the spirituous qualities, obtained by fermentation, are of a thinner and more penetrating nature, which may be compared with that of alcohol: therefore, for all philosophical and chemical reasons, totally refrain from steeping the hops in liquor [that is, water, before boiling them with the wort]; and avoid, by all possible means, the evaporation of the aromatic quality, when it can be retained by the adoption of means already recommended."

3. *Cooling.*—The next process is that of cooling; and it is of great importance that this should be effected as rapidly as possible, because, otherwise, the oxidating influence of the atmosphere would convert the saccharine matter into an acid, and, consequently, vinegar, instead of ale, would be the result. By the older (and still used) methods, the hopped-wort was exposed, in extensive shallow trays, to the cooling action of the air in an upper portion of the

* It may be here of advantage to the unpractical reader, to state, that the term "back" is applied generally to large wooden and other vessels, intended to hold liquid in brewing, dyeing, and similar operations.

brewery. A whole floor, under such arrangement, with holes and louvre-blinds in the walls, was used. The beer was pumped up on to this floor, and so left to cool. But a new method of refrigeration is to be preferred. It is that of driving cold water through metal pipes surrounded by the hot wort, the heat of which is rapidly absorbed by the metal, and carried away by the water passing through them. The water is usually derived from the supply-well of the brewery; and, if drawn from a great depth, its temperature will not exceed 48° all the year round, in our climate. Of course, power must be employed for the purpose; and the steam-engine is the most eligible source. The water need not be wasted; for, if pumped into the liquor-back, its increased temperature, derived from the hot wort, causes a saving of coals, by supplying hot instead of cold water for the mash-tun, scalding casks, and other purposes.

The wort is passed to the cooler through the hop-back, which has perforations that allow of the passage of the wort, but retain the hop and other solid matter, if accidentally present.

4. *Fermentation.*—This is the last process of a chemical nature which the extract of malt undergoes. Its object is to convert the greater portion of the sugar in the wort into alcohol, or "spirit;" hence the intoxicating effect of malt liquors. As we shall see, when describing the art of distilling, the distiller pushes fermentation on until *all* the sugar is converted into spirit. The brewer does not proceed so far, but leaves a portion of the sugar, to a greater or less extent, according to his wish to produce a sweet or bitter ale; and generally, also, in respect to its influence on the flavour of the ale.

By reference to p. 470, it will be seen that three sorts or species of sugar are known—*cane sugar*, or *sucrose*, obtained from the sugar-cane, maple, palm, beet, &c.; *grape sugar*, or *glucose*, found in all ripe fruits; and *milk*, or *animal sugar*, called *lactose*, which occurs in milk. Now, chemically, it is only the grape sugar that the brewer has to deal with; for although he may, and does use, at the present, large quantities of cane sugar with malt, still, as we have shown at the page just referred to, cane sugar is converted into grape sugar by the action of yeast, at a temperature of about 80°. It is for this reason that we have omitted any but the bare mention of sugar in brewing; for it may, practically, be considered in solution simply as wort, so far as the subsequent chemical processes that the wort has to undergo are concerned.

Yeast is universally employed to produce fermentation, both by the brewer and the distiller. Its action on the sugar is singular; for whilst converting that into spirit, or alcohol, it undergoes no change itself, but rather considerably adds to its quantity. In philosophical language, such action is called *catalytic;* an instance of which is seen in the results produced by the metal platinum on the mixed gases, oxygen and hydrogen. If these two were put into a clean bottle, carefully stoppered, no chemical change would take place. If, however, a piece of spongy platinum, or a slip of the foil of that metal, perfectly clean, be put into the bottle, the gases will gradually heat the metal, ignition will take place, and water be formed. Yet the platinum is not in the least degree changed. So, in using yeast to ferment saccharine matter, an analogous effect results.

Yeast pertains, in its nature, to the fungus family, all of which have a greater or less power of creating an action of a fermentative character in vegetable substances. For the brewer's purpose it should be as fresh as possible. It is prepared for use by adding a quarter of its weight of wort, at a heat of 80°.

The wort is run into the gyle-tun, and the yeast simultaneously added. An excellent plan is, to have the tuns, if possible, below ground, with closed tops, fitted with a safety-valve; for the result of fermentation is to produce heat with great disengagement of carbonic acid gas; and this latter, if not allowed ready escape, would cause the tun to burst. But, with the safety-valve, an increase of pressure is kept up in the tun, by means of which an increased amount of carbonic acid is retained by the beer, which is thus rendered more lively to the palate, and brisker when drawn for drinking. Closed tuns, however, cannot be skimmed; hence the newly-formed yeast must be removed by being drawn off. The temperature of the time of year is a matter of importance; and hence all first-class brewers make their best articles between October and March, when the low external temperature of the atmosphere permits a ready means of regulating the heat of the fermenting wort, which is carefully noted, from time to time, by means of a thermometer. "The first visible signs of fermentation," remarks the author already quoted, "are in a delicate white line all round the gyle-tun, which increases gradually until the whole surface is covered with a thin cream, which rises very gradually; it then breaks out into a fine cauliflower-head, increasing in size and depth until it again resolves into the spinal or rocky-head. The next change is into a head with a smooth surface, which produces the first indication of yeast, and grows thicker and heavier towards the cleansing-point, when skimming or separation is necessary for the discharge of the yeast. The skimming is to be repeated every two or three hours for the first twelve hours; or it may be drawn off at the cleansing-point into casks, filled up full to the bung, every two or three hours for the first twelve hours."

A temperature of 70° is that which is usually kept up while fermenting; and the amount of fermentation requisite is ascertained by the gradual lessening of the gravity of the wort, which is carried on until the latter is reduced to from one-third to one-fourth of its original gravity.

By neglect in respect to the temperature of the mashings (described at p. 485, *ante*), and from a variety of causes, fermentation may result in the production of an acid, through which a portion of the liquid will be lost, and the whole much injured in respect to its flavour

and power of keeping. The experienced brewer has, therefore, not only to be very careful in the act of fermenting, but also in the various antecedent processes, or he may incur serious loss through inattention to such important particulars.

Racking and *Cleansing* are the next operations to be effected. The beer is drawn off from the fermenting-vat into smaller vessels, as represented in the following cut. The yeast gradually

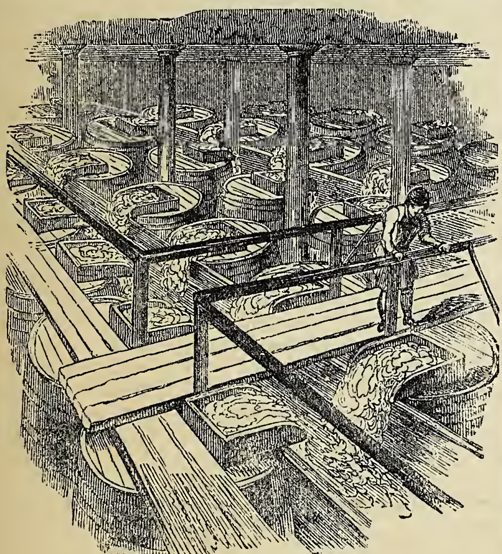


Fig. 359.—Working of Beer.

rises to the surface, and escapes from the vessels through troughs, which lead it to a larger receptacle, whence it is removed until required for fresh brewings. The beer is afterwards drawn off into store-vats of immense size, where it is kept until sent out, hops being added according to the taste of the customers that the brewer has to serve.

We have thus endeavoured to trace all the steps of beer-brewing, from the operation of converting barley into malt, until the beer is ready for the use of the consumer, having, necessarily, omitted some points of minor importance, and that are purely technical in their nature.

The distinctive appellations of each kind of beer brewed in this country, are too well known to require enumeration. Porter, until recently, was especially a characteristic article. Of late years, the fine bitter ales of Burton-on-Trent have advanced equally in public favour throughout the world; whilst stout and old ale have, so far as we can learn, remained stationary, or, perhaps, receded in consumption. Table-beer, "fourpenny ale," and "cooper"—the latter a mixture of stout and porter—are very popular forms of drink amongst the working classes, together with porter.

We are by no means the largest beer-drinking nation in the world. Bavaria, we believe, deserves the palm of this qualification. The breweries in that country are very numerous, and the consumption of the article enormous. Even in some parts of France, but especially on the route of English travellers to, and in Paris, our malt liquors, as pale ale and stout, are largely consumed; so that really, whilst recent fiscal changes in our country encourage the consumption of French wines, the French themselves have largely patronised our British beer.

We have already noticed, in the previous pages, the substitution of cane sugar for a portion of malt in brewing. Of course, this leads to the production of beer at a lower price by the brewer; for 180 pounds of good cane sugar will be equivalent to a quarter, or 352 pounds of malt, the price of the latter being, on an average, not far from double that of the sugar. In country places, and for domestic brewing, sugar has long been much used. It has the advantage of saving much trouble in the mashing process, which is simply intended to dissolve the grape sugar from the malt. Of course, simple solution of the cane sugar, or its molasses, is sufficient; and, as already stated, yeast, at a temperature of 80°, first converts it into grape sugar, and then into alcohol.

It is not to be expected that an article of such enormous consumption as beer, in any of its forms, would escape adulteration, now universally practised on almost every article of food, drink, and even clothing. Vain has it been that acts of parliament have been passed to restrain such practices; for, although many parishes in this country have availed themselves of the powers of the last act, and appointed a public analyst, generally the act is a dead letter. Residing in a metropolitan suburban parish, with a population of, now, perhaps, 280,000, we may state, that the public analyst had only two cases submitted to him of adulteration of any article in twelve months, although we have the opinion that a two hours' examination of the majority of the streets, would furnish, from the public-houses, and various retail food-shops, work for half-a-dozen competent analysts for a week. One road might be chosen as a sample, containing from twenty to thirty public-houses and beer-shops, only two or three of which it is really safe to enter for beer-drinking, except to persons of extraordinary strong constitution. A relation long connected with, perhaps, the most eminent brewery in London, has assured us, that nothing would induce him to drink any article purchased at these public-houses; and yet a population of several thousands of shopkeepers, artisans, and others of the working class, exist in, and adjacent to it. A personal friend, the late Dr. Normandy, who was so well known for his abilities as an analytical chemist, and more particularly in regard to food adulteration, related to us, that one day, overcome with thirst, he entered a "highly respectable" public-house, at the east end of London, and asked for a glass of porter. Within half-an-hour of drinking it he was taken very ill, but returned to the public-house, and purchased a pint of the precious liquid. On getting home to his laboratory, and analysing this porter, he

found it to contain several grains of green copperas; that is, sulphate of iron, a poison most injurious to the stomach, and only used in medicine, in minute quantities, as a styptic.

The object of using copperas is that of giving and keeping up a head on the beer. The price which the retailer pays for his porter to any of the leading brewers, renders it impossible that he can sell it at a profit at 3*d.* per pot—the usual price in middling or low localities. Consequently, the retailer, on receiving the beer in his cellar, has to start the operation of "cellar work," which is, to clear it by finings, generally supplied by the brewer for the purpose; to add some foots sugar; and, lastly, "liquor," vulgarly known as water. Here the respectable retailer stops; and so far we will not complain of any of the preceding steps, because the brewer must make his beer of sufficient strength to keep, for he cannot tell how great or small the demand may be for it. Hence, when it gets into the retailer's hands, who knows almost exactly what his sale is weekly, there seems no reason to complain of his doing what we have described, because he only does that which would, most probably, have been done in the brewery, to equalise questions of cost and profit by means not in any possible way objectionable.

But if we go a step further, into what is called a "cutting trade," a very different state of things is adopted. More water must be added to the porter to admit of sufficient profit to pay the retailer at the selling price of 3*d.* per pot. But too much water will flatten the beer, destroy its "head," or froth, when poured into the pot, and, moreover, so weaken it as to give it a watery taste to the palate. Consequently, means must be adopted to keep up both head and strength; and this has given rise to the establishment of a trade, known as the brewer's or publican's "druggist." This worthy concocts his ingredients from many sources, and contrives thereby to sell to the retail publican an article that will, so far as taste and intoxicating, or rather stupefying effects go, cure or remedy the results of over-watering the genuine porter. Thus, by using *Cocculus indicus*, the seeds of the *Anamirta cocculus* of the East Indies (a deadly poison, of a narcotic character), the head-thickening power of the porter is restored. By means of grains of paradise—pungent seeds of the *Amomum melegueta*, a species of pepper—pungency, or the "biting" effects that the carbonic acid of good beer produces, are imitated. By the addition of copperas, as already mentioned, the head of porter may be kept up for a day or two if poured into a glass, although the really good article would lose every vestige of head in a few hours. Salt, caramel or burnt sugar, tobacco-juice, and a long list of other adulterations may be effected; and, indeed, considering the enormous extension of the retail trade, it is really surprising that comparatively few houses, except in good neighbourhoods, supply a genuine article.

To any remonstrance against such adulteration, it is replied, that people prefer such porter, because it is livelier, and more stimulating to the palate—an argument to confute which, on the grounds of honest trading, common sense, and uncommon (we regret to say) morality, would be quite unnecessary for any honourable trader. But such is not the case; for a good article, at a high price, will sell. An example of this kind occurred within our personal knowledge. An individual who had risen from being a common drayman to be the owner of a small public-house, in one of the lowest, most crowded, and most "operative-resident" parts of London, determined to sell only the genuine porter, as supplied by one of the most eminent London brewers, and at full price. In the course of a few years he had amassed a considerable sum of money. He took a house some distance from London, whither his previous honourable trading attracted many of his town customers on holidays, and was enabled to retire from business; but, disliking the reaction of too quiet a life, he returned to the scene of his earliest trade, purchased a plot of ground, built a new house, and, by pursuing his previous honest practices, has acquired the largest trade in the neighbourhood, although five old-established houses are within a stone's-throw of the new one.

We relate this anecdote for two purposes. Our book will most probably fall into the hands of two classes—those who consume, and those who retail beers. To both of these we commend the preceding facts: on the one hand, that the buyer may preserve his health, and encourage the honest trader; and, on the other, to persuade the retailer to do that which is lawful and right, so that he may save the bodies of his customers, whilst he is putting money into his purse.

It has been related to us, by a mutual personal friend, that a late eminent physician would never drink any but bottled malt liquors. The reason of this is obvious. No sane man would bottle anything but the best beer (here we include all kinds); for if he were careless on this point he would be ruined, because the beer would not keep—most likely it would all turn to vinegar. Besides, bottled beer must first have been brewed of such a quality as will permit it to keep. Like port wine, if good when bottled, it improves by age; but, otherwise, becomes valueless. We have tasted Scotch ale (really good when first bottled) twelve years after bottling, that was far superior, in all respects, to the majority of champagne now usually sold. And so with all bottled beers the rule holds good—that a first-rate article must be employed, or a dead loss will occur to the bottler.

All beers brewed from pale malt, such as ales, are less liable to adulteration than porter and stout, because they are generally too delicate to be tampered with; and, for this reason, are preferable for retail purchase, in small quantities, for present drinking. It is not, however, every one that can partake of ale; and it may be remarked, that the physiological effects of ales, and of porter or stout, are entirely different on the same or various persons. This is a matter, however, on which we cannot enter, as it pertains essentially to chemistry as applied to medicine.

Nor can we put our unpractical readers in possession of simple methods of analysing beer. Salt, which always is present in some proportion, may be judged of, as regards its comparative amount, by adding to a wine-glass of the beer to be tested, a solution of nitrate of silver, as long as any precipitate falls down; and, by filtering this precipitate through white blotting-paper, and drying it, the quantity of salt may be roughly ascertained in different beers so tested. Copperas is readily detected; for if, to the suspected beer, a little solution of the yellow prussiate of potash (ferrocyanide of potassium), that may be procured of any chemist, be added, a grayish-white precipitate will be afforded. If this and the liquid be thrown on to a plate, and exposed to the air, the white powder will turn to a dark blue, producing common Prussian blue, the quantity of which will depend on the amount of copperas in the beer. The detection, by these simple methods, of either salt or copperas, should at once lead to a communication with the public analyst of the district, who will, no doubt, do his duty in respect to the offending party. The detection of tobacco, grains of paradise, *Cocculus indicus*, &c., &c., is far too difficult and delicate a matter for all but the experienced chemist, who, indeed, will himself find it no easy task to arrive at satisfactory results.

DISTILLATION OF BRITISH SPIRITS.

Under this head (generally stated, at the commencement of this chapter, as distilling), all the operations of obtaining spirituous liquors may be conveniently and completely described; because, from whatever source alcohol is produced, the method of obtaining it in a concentrated form is identical. We have preferred, however, to use the above heading for this department of our subject, because as malt, or rather corn, is the sole source of the "spirit" produced in this country, the future remarks are more properly connected with the preceding subjects of malting and brewing than with any other with which we shall have to deal.

Distilling is an art of the simplest character in principle. It is only the separation of two liquids that evaporate at different temperatures. That which vaporises at the lowest temperature arises first as vapour by the application of heat; although generally, perhaps always, mixed with the other liquid, that requires a higher temperature to be converted alone into vapour. When that vapour is formed, as it owes its vaporised condition to containing latent heat, the next step is to abstract this hidden heat, and so to re-convert the vapour into a liquid form. Instances of distillation are of common occurrence in the rough form. Thus, if water be heated in almost any vessel of tolerable size, and having some slight access to air—as in the common tea-kettle—whilst the water boils at the lower part of the vessel, some portion of the vapour is condensed or returned to the liquid form, and found as a kind of dew on the lid. If to the spout of a tea-kettle a few feet of pewter tube be attached, and this tube be covered with wet cloths, water will trickle out at the further end of the tube so long as steam is produced, for the evaporation of the moisture of the wet cloths on the tubes robs the steam of its latent heat as it passes through the tube, and so, removing the cause of the vapour, restores it to the liquid state. Hence water so distilled, and largely employed by the practical chemist in his experiments, is emphatically termed *distilled* water.

An ordinary still, and the principles of every form of still, will be properly described and understood by reference to the following engraving.

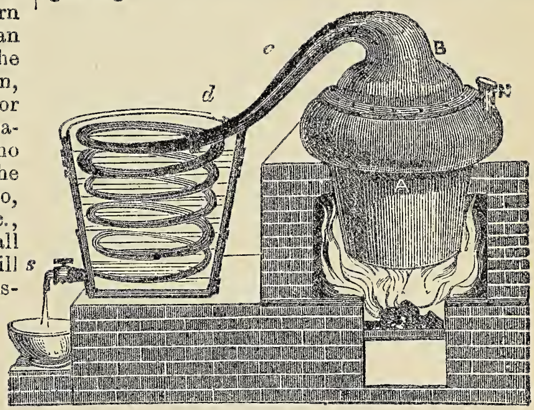


Fig. 360.—The Still.

A represents the body of the still, in which the liquid to be distilled is introduced. It is fitted with a head or top, B, which gradually narrows by extension from *c* to *d*. At the latter point it is connected with a metallic worm or pipe, turned into a helix or screw-like form, and enclosed in any convenient vessel kept constantly filled by cold water. The latter is supplied at the bottom of the vessel, whilst the water that gradually gets heated in it runs off at the top, for hot water being lighter than cold, naturally rises, and so overflows from the vessel. At times, however, this plan is not exactly followed, because if the water be sent into this condenser, as it is called, with any force, it speedily finds its way to the lower part.

The method of using the still is as follows:—The liquid to be distilled is introduced at an opening, N, so as to partly fill the body of the still, A. A fire is then lit beneath A; and, at last, the liquid becoming heated, its most vaporous part first escapes by B, through the pipe, *c*, to the condenser in *d*, as shown by the worm surrounded with cold water; and this vapour, being thus robbed of its latent heat, is again converted into a liquid, and escapes by an opening, *s*, into any suitable vessel placed to receive it.

Such is an outline description of the usual mode of distillation adopted for producing spirit from malt liquors, as whiskey, &c.; from wine, as brandy; and from molasses, or sugar, as rum.

It must not be forgotten, however, at this stage of our remarks, that although distilling also includes rectification, the two are, practically, distinct operations. Thus, the first product of the *distillation* of corn liquor is an offensive spirit, utterly unfit to drink; but by rectification, as we shall hereafter see, that raw spirit is converted into "spirits," that take the name of whiskey, gin, Hollands, brandy, liqueurs, &c., according to certain methods adopted to give special flavours to equally special spirituous liquors.

According to Mr. Barlow, in his observations on distilling, the art, with the view to the production of spirituous liquor, seems to have been the invention of a Frenchman, in the thirteenth century, of the name of Villeneuve, who was a distinguished chemist, or alchymist, of that date; from which time, to the commencement of the present century, slow but progressive ameliorations were introduced. But since that time, the progress of improvement has been very rapid and important. M. Dabrunfaut, in the *Treatise on Distillation*, gives, also, the honour of the first great step towards the modern practice to another Frenchman, M. E. Adam, whom he states to have been an "obscure person, unacquainted with science, and ignorant of the art he undertook to improve [but who, notwithstanding, established a new system]; and, with a giant's pace, arrived at that point which the most profound geniuses had never been able to attain after the continued labour of many centuries." "If," he continues, "Raymond, Lully, Lavoisier, Meusnier, or Fourcroy, had made such a discovery, one might have admired their genius without being surprised at their science; but that a man who had not even the first notion of the art in which he was engaged, and who had not the least experience in the manual operations, should rise all at once, and, at first trial, ascend to the acmé of the science, is certainly extraordinary. Adam was the inventor of a most ingenious method of distillation, adopted from the Woulfe bottle system, in which three or four bottles, arranged con-

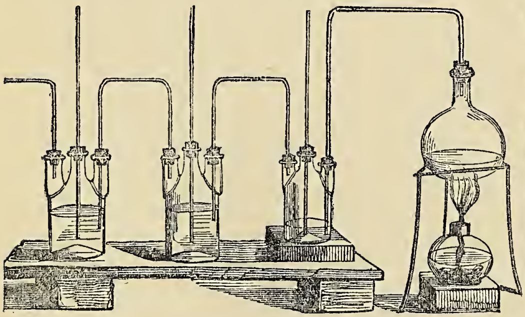


Fig. 361.—Woulfe Bottle-still.

secutively, receive the products of distillation, or gas production. The vapour or gas passes, in this arrangement, from the still or flask, in such a manner, that the last of the series shall condense the purest form of the vapour or gas. Adam applied it in the large way for alcohol from beer or wine, by bringing a tube from the capital of the still [see Fig. 360 at B, p. 489, *ante*] into a large copper recipient; by another tube this was joined to a second recipient, through a series of four vessels, arranged according to the plan proposed by Woulfe. [This is represented in detail, in respect to the method adopted by practical chemists, by the preceding cut, in which the successive arrangement of the bottles is shown; and which is similar to Adam's distilling plan now in course of description.] The last vessel is then made to communicate with the worm of the first refrigerator, by which means, the body of the still, and the two recipients nearest to it, are charged with the wine, or fermented liquor; and when ebullition takes place in the still, the vapour arising from it soon communicates the boiling temperature to the liquor in the two recipients; from these, the volatilised alcohol will rise, and pass into the third vessel, which is empty. After imparting a certain heat to it, a portion of the finer or less condensed spirit will pass into the fourth recipient, and thence, in a little time, into the worm of the refrigerator. The wine round the worm will also acquire heat, but more slowly; therefore, the vapour, which, in consequence, may pass uncondensed into the first worm, is conducted into a second, surrounded with cold water. Whenever the still is worked off, it is replenished by a stop-cock from the nearest recipient, which, in its turn, is filled from the second, and the second from the first worm-tub. It is thus evident, that, by keeping the third and fourth recipients at a certain temperature, alcohol may be formed, of any degree of lightness, at the remote extremity of the apparatus; by which a great economy is effected in the expenditure of fuel, and the flavour of the spirit much improved."

This and many other improved forms of the still have not been used in these islands, because fiscal reasons prevent their adoption. In fact, we noticed that, at Campbelton, in Argyleshire, Scotland, on our last visit, a short time ago, the general method of distillation, except in minor mechanical arrangements, did not differ from that described at p. 489, *ante*, and illustrated by Fig. 360. At the time we refer to, about thirty-four distilleries were in operation, and, of course, their united production has placed that beautifully-situated town at the head of any localities producing raw spirits in our island, although any individual establishment is far exceeded in size by many others in various parts of Scotland, where distilling is more largely carried on than in any other part of the kingdom, taking all circumstances into consideration.

It is, of course, to the interest of the distiller to raise the liquid, or "wash," as rapidly as possible into vapour, and as rapidly to condense it; and abroad, this, owing to the absence of government regulations, is readily effected; hence numerous ingenious stills, &c., of all kinds have been adopted, that are manufactured in this country for foreign use, but may not be em-

ployed here. An ordinary form of the British kind, differing nowise in principle from that described at p. 489, *ante*, is represented by Fig. 362, only the furnace-bed of the still, its

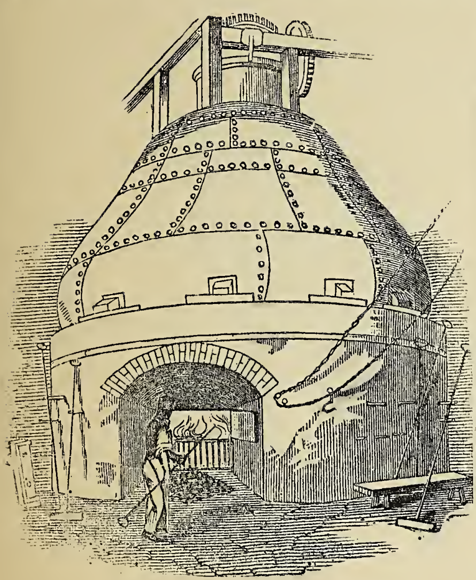


Fig. 362.—Spirit Still.

upper portion, and minor arrangements, being represented.

We have already pointed out the distinction that subsists between the first production of the spirit from corn, &c., and the rectification that succeeds it, so as to fit the raw spirit for drinking purposes. This distinction is again alluded to, so that it may be borne in mind; more especially as, by law, the two processes of distilling from corn, &c., and the rectification of the spirit so produced, are not allowed to be carried on in the same premises, nor within a quarter of a mile of each other. In a certain celebrated case, however, the government of the day, some years ago, was cleverly defeated by an eminent firm, who converted old water-pipes, connecting a distillery and rectifying firm, by pure accident, into a means of communication: and, doubtless, an enormous profit resulted. The reason why this prohibition exists is, that, as the government charges duty on the spirits in proportion as they have less specific gravity, it would be practically impossible to do so on rectified spirits; because every addition in the shape of flavour, sugar, &c., raises the gravity without really diminishing the amount of pure spirits to an equal extent in the same bulk of fluid. But this will be better understood when we describe the methods that exist, and are adopted, for ascertaining the strength of spirituous liquors.

Despite all attempts at discovering fraudulent or secret distillation, there is no doubt that it is carried on, at the present day, to an enormous extent. At p. 488, *ante*, we have described some of the tricks of adulteration that are adopted in respect to beer, especially porter; and, in regard to gin, whiskey, and brandy, it is notorious that, in all low localities, illicit spirits are largely used for the purpose of adulteration. But a few years ago, whilst partaking of luncheon at the private bar of a London tavern, a woman entered by a bye-door, to sell six dozen half-pint bottles of lavender-water!! Having a partiality for that perfume, we desired to purchase but one bottle, but was refused, on the ground that the mistress of the establishment had bought the whole—certainly a rather extravagant investment in a luxury, the doom of which we fancied was the gin or whiskey-vat rather than the toilet-table. Instances have been known of females remaining far longer than physiology teaches in a delicate condition, who have suddenly saved the interference of medical assistance by stabbing themselves with a penknife, when not their hopes alone, but those of the exciseman, who was exercising an impertinent interference, came to an untimely end. An aged relation, for fifty years connected with the excise (1781—1831), related, amongst scores of successful and unsuccessful attempts at illicit distillation, the following, which, as far as memory serves us, occurred in the neighbourhood of Newcastle-on-Tyne, which he discovered by the following specimen of sagacity:—A respectable farmer had long been suspected of illicit distillation for many reasons, but had as long escaped detection. The officer to whom we allude determined, if possible, to discover the truth of the matter; and, taking with him some of his subordinates, went to the farm, and closely examined every part, but in vain. At last it struck him that the fire in the kitchen grate was far larger than the time of year, &c., required, and he boldly determined to have the whole construction removed. After the most violent protestations on the part of the farmer, this was effected; and, behold! in a cellar beneath was an extensive distilling apparatus in full operation, with every requirement of the trade or manufacture.

Having thus described some of the most important principles of the art of distillation, or distilling, the practical part must next receive attention.

The material from which malt spirit is extracted is not necessarily all malt. On the contrary, from motives of cheapness, a large proportion of raw grain, with a small one of malt, is employed. Of course, on raw grain no duty is paid; and barley is not alone necessary; for wheat, rye, oats, Indian corn, as seeds; potatoes, beet, and, indeed, almost any starch vegetable, may be employed; for, as already described at p. 472, *ante*, all such substances can be made or converted into grape sugar, and, subsequently, into spirit, or alcohol, by fermentation. Even a shirt, or pocket-handkerchief, and other articles of cotton or linen manufacture, may be, by chemical processes, converted into whiskey, gin, and British brandy—so astonishing are the results that chemistry affords us. In Norway, and other parts of continental Europe, potatoes are there employed in the manufacture of coarse brandy, each

farmer becoming his own distiller; and, if statistical accounts are true, doing full justice to the article of an intoxicating nature they produce; for the average consumption per head of population, in some of those countries, reaches eight gallons annually, or nearly six times the highest average of any part of our own islands. We shall, however, here confine our attention only to the production of spirit from grain.

The preliminary operations of the distiller are exactly similar to those of the brewer. Sweet wort is first produced from the mixed grain, the malt being crushed, and the raw grain ground, and both committed to the mash-tun, a form of which, with overhead machinery for the purpose of stirring the grain well up in the tun, is represented in the following engraving; where,

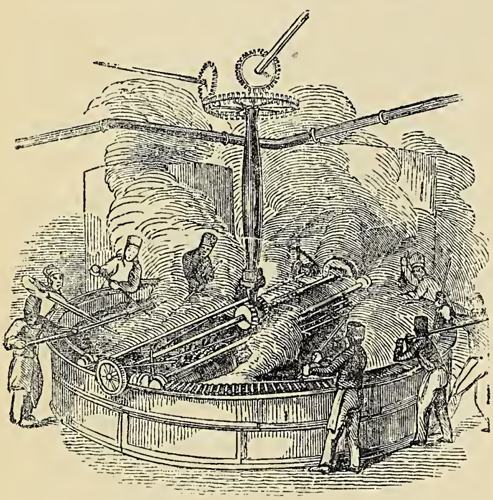


Fig. 363.—The Mash-tun.

also, is illustrated the mode of stirring with oars. Both of these methods, with the precautions necessary in proper mashing, have been already explained at p. 484, *ante*. When the mashing is complete, the wort is run off into the underback, and thence passed to the coolers, just as we have described in respect to brewing. When cooled, it is fermented to such a degree as will convert, as much as possible, *all* the sugar into alcohol; for whilst it is the interest of the distiller to get as much alcohol as possible from the sugar, the brewer retains a portion of it, as forming, in part, the flavour of the beer. The resulting product is called "wash;" and, in this condition, the liquor is conveyed to the wash-still, already illustrated and described at p. 491, *ante*, Fig. 362. The wash contains a considerable proportion of proof spirit, perhaps from 10 to 12 per cent., equal to from 5 to 6 per cent. of perfectly pure or absolute alcohol.

Heat being kept up by the furnace beneath (and here we may mention that steam-heat has been substituted in certain instances for the naked fire), the spirituous portion of the wash evaporates at a lower temperature than the water with which it is mixed; but a portion of water also passes over. The steam or vapour passing through the worm (see Fig. 360, p. 489, *ante*) becomes condensed, and the first product of distillation is collected. It is technically called "low wines." The strength of these is tested by a hydrometer, the principles of which, and its use, we shall presently describe; whilst the practice of the plan is illustrated in the following engraving, in which the workman is repre-

Fig. 364.—Testing "Low-wines."

sented as forcing down gently the hydrometer into a glass cylinder holding the liquid, and observing the indication at the level of the liquid on the stem of the hydrometer; for at the point where the hydrometer settles down, and the liquid is level with any portion of the stem, the specific gravity of the spirit or "low wines" is shown.

By successive distillation the water can be gradually removed, whilst the spirit thrown over at each fresh distillation becomes stronger, and acquires less specific gravity; and by the use of the hydrometer the spirit may be obtained of any required strength by the distiller. In the intermediate steps, until raw spirit is obtained, the results of distillation have applied to them names, as follows:—Strong low wines; weak low wines; strong faints, and weak faints—according to the strength arrived at.

Absolute alcohol—that is, spirit entirely free from water—can only be obtained by leaving "spirits of wine" (the strongest form of alcohol sold) in contact with fresh-made lime, and by subsequent distillation. In this form, as a true chemical compound, such alcohol has a specific gravity of about 0·794, reckoning water as 1·000; in other words, 794 gallons, quarts, pints, &c., of this spirit, will occupy as much space as 1,000 such quantities of distilled water, both being of the same temperature. Spirits of wine, as

usually sold for varnish-making, medicinal and other purposes, should contain about 85 per cent. of pure or absolute alcohol, and 15 per cent. of water, and possess a specific gravity of 0·840.

Proof spirit, as recognised by the excise laws in fiscal regulations, is considered to be a compound of 49·25 per cent. of absolute alcohol with 50·75 per cent. of water, with a specific gravity of 0·92 at 60°. Hence the terms *over* and *under proof*, according as a spirit exceeds or falls below that strength. The best London gin never exceeds a strength of 17 per cent. under proof—the highest allowed by law; but raw spirit and Scotch whiskey, before reduction, are sold at various strengths above proof, that consequently regulate their value in purchase by the rectifier. The strongest brandy, rum, and Hollands average about 50 per cent. of spirit, having a specific gravity of 0·825, which is the strongest form of alcohol, called spirits of wine, and stronger than that usually sold in commerce, which, as previously noticed, has an average specific gravity of 0·840.

Raw spirit, as thus prepared, is unfit for use as a spirituous liquor for drinking purposes. According to the sources from which it is obtained, it is especially flavoured by an offensive oil, called fusel or potato oil, which it is the business of the rectifier to remove. This is done by re-distillation, whilst flavour is given by the addition of coriander and other seeds, juniper berries, &c., if gin be desired; whilst the natural flavour of the corn oil is left in both Irish and Scotch whiskey—hence what is called the "smoky" flavour. Any flavour may be communicated to pure spirit by distilling it with essential oils or flavouring substances; hence the variety of flavour of cordials and other spirituous liquors.

Formerly the fusel oil was a waste product, of no use except for burning; but by a most singular and interesting series of chemical changes, which we shall briefly explain, it is not only now of value, but a very large source of flavours for confectionery, in place of fruits or their essences.

To make our non-chemical readers acquainted with all the details of the subject would occupy too much space, and be wearisome to them. We may briefly state, however, that alcohol is considered as the oxide of a base, called *ethyl*, and united with water; hence it is called the hydrated oxide of ethyl; just, in fact, as slaked lime is the hydrated oxide of calcium—a metal which, with oxygen, forms lime. The ethyl, therefore, although itself a compound of carbon and hydrogen, is yet capable of acting precisely as if it were an elementary or simple body.

Ether is a volatile liquid, obtained by distilling alcohol with various acids; that produced by the action of sulphuric acid on alcohol, or spirits of wine, being known as sulphuric ether, and is of great use in medicine as a stimulant, and for other purposes. If, in place of such materials, rancid butter be treated so as to extract its acid, called the *butyric*, or butter-acid (which is the cause of the rancidity of butter and cheese), and this acid be distilled with sulphuric acid and alcohol, *butyric ether* is produced. This has precisely the same flavour as the pine-apple, and is now largely used in place of that fruit in producing various articles of confectionery with that flavour.

Now another such base as *ethyl* exists, and has received the name of *amyl*. The fusel oil, or potato oil, that we have described as the waste of the rectifying process, has precisely the same relation to amyl that alcohol has to ethyl; that is, it is a hydrated oxide of amyl, just as alcohol is that of ethyl. And, again, like alcohol, it is capable of forming an oxide of amyl, or amylic ether, by distillation with sulphuric acid. Therefore, pursuing a similar course with it as was mentioned in respect to butyric acid and alcohol, analogous results may be obtained. Accordingly, by distilling together one part of the crude oil, or amylic alcohol, with two parts, by weight, of acetate of potass and one of sulphuric acid, an acetate of the oxide of amyl is produced, having precisely the flavour of the jargonelle pear; and that is now substituted for the fruit, in a similar manner, in confectionery, as that already pointed out, in regard to the flavour of the pine-apple, as obtained from alcohol. By substituting valerianic acid, a flavour similar to that of the apple, and of like use to the above, may be procured.

These results, which we have explained as clearly as can be done without deep examination into the principle of all the changes that occur, afford a remarkable instance of the progress of applied chemistry of late years; and are only equalled in their surprising character, to the uninitiated in science, by the equally astonishing fact, that coal, when properly treated, affords, amongst other valuable products, ammonia, or smelling salts, a substitute for bitter almond oil, and those beautiful coal-tar dyes, now universally employed by the dyer and calico-printer.

The distillation of rum and brandy, although slightly varying in detail, is precisely similar, in general principles, with those already described. Rum, of which so large a quantity is imported into this country from the West India Islands, is produced by molasses, which have been already described as a product of the cane-juice, and uncrystallisable (see *ante*, p. 472). The quantity produced on a sugar plantation is very great, equalling from 50 to 75 per cent. of the saleable sugar. These molasses are utilised by fermentation and distillation, each gallon being thus made to produce a gallon of rum. Much "British rum" is made in this country from corn spirit, by distillation with flavouring obtained from some of the artificial essences just described, and other sources; but it is far inferior to the genuine article.

Brandy is produced by distilling inferior wine, both red and white; and also from the skins of grapes that have been pressed to make wine. When first distilled, it is colourless; and, if left alone, only gathers colour by age. The brown brandy, and much of the pale, however, imported into this country, is coloured by burnt

sugar, and other matters. The choicest brandy is that of the department Charente, in France, especially that made in the vicinity of Cognac, which, however, lends its name to a variety of compounds, the production of which takes place much nearer to London than Cognac. British brandy is simply corn spirit of a pure kind, flavoured and coloured. A large quantity of our raw spirit is exported to the continent, that, in due time, is returned as *Eau de vie de vin;* the two last words being evidently a misnomer, considering that such brandy is the production of British corn rather than of foreign grapes. But, "where ignorance," &c., &c.; and, consequently, as the drinker knows no better, he is, perhaps, not much the worse for the fraud practised on his pocket and palate. It is well known, by the initiated into the secrets of the wine and spirit trade, that far more "port wine" and "brandy" is consumed in this country than we import from all others. Hence a prostitution of science, ingeniously applied to the profit of the seller, and, very frequently, to the serious injury of the consumer. The source of the alcohol of wine-brandy will be described, together with the art of wine-making.

We conclude this account of the art of distilling, &c., by giving some particulars of the methods usually adopted to ascertain the specific gravity of spirituous liquors, as followed by the excise, the distiller, the rectifier, and the retailer.

It is evident, that if a bottle be filled with water, exactly holding 1,000 grains of that liquid, and if, in place of the water, a lighter or heavier liquid be weighed, for the same bulk, the indicated weight would be less in the former, and greater in the latter case. Hence a bottle holding an exact measured and weighed quantity of water, can be used to ascertain the specific gravity, or relative weight, of any other liquid, the same bulk being operated on, exactly, in all cases.

But by means of the hydrometer, a much readier means exists than that of weighing; and by that instrument, consequently, the specific gravity of nearly all liquids employed in every kind of manufacture is taken, as in bleaching, dyeing, spirit-distilling, rectifying, &c.

Fig. 365.

The most universal form is that illustrated in the annexed cut; and it consists of a glass stem, *a*, in which is enclosed a graduated paper scale, running above and below 1·000, which indicates the specific gravity of distilled water at 60° Fah.; *b* is an air-bulb, the object of which is to float the instrument in any liquid; *c* is a smaller bulb, containing mercury, and intended to steady the hydrometer when floating in the liquid under examination. Generally speaking, to make the instrument more delicate, it is sold in sets, for different specific gravities; but we shall only consider one, supposing it to be capable of measuring all specific gravities from 0·700, below 1·000 of water, to 2·000, or double that of water.

Now, if such an instrument be immersed in distilled water at 60°, let us further suppose that the level of the liquid is exactly coincident with the external mark, indicated by the line *d;* but which, in the instrument, would be shown by the mark 1·000, inside the stem *a*. If now the water in the vessel (which should be a tall glass cylinder) be poured out, and proof spirit be employed, the hydrometer being heavier, bulk for bulk, in the spirit than in water, will sink, until, say, the level of the liquid is at *e*, and which, by the index, would indicate 0·92. If the spirit be now poured out, and a solution of weak salt and water be poured into the vessel, the hydrometer, instead of sinking, will rise even above the level that it indicated with the distilled water, because the salt and water is heavier than pure water; and we will accordingly suppose that the level of the liquid is indicated by *f*—say a specific gravity of 1·10.

Thus the *sinking* of the hydrometer below *d*, indicates a liquid with *less* specific gravity than water; and its rise above *d*, shows a *greater* specific gravity than water; and, by properly graduating the scale in the manner illustrated by the preceding example, an instrument is afforded by which the specific gravities of any liquid may be accurately ascertained. Such an instrument, used generally, is called the *hydrometer;* but specially, if for sugar in solution, it is termed the *saccharometer;* for milk, the *lactometer;* for urine, the *urinometer;* and similarly, according to the special purpose to which it is applied.

So far for the science of the instrument; but, perhaps, our non-scientific reader may understand us better if we give two much more popular illustrations. If a ship be loaded in any of the docks near London, in the fresh water of the Thames, so that the water shall just reach her open ports or windows at the sides, and she be towed down to the Nore, she will gradually *rise* out of the water, and continue to do so until she reaches the sea, because at every mile of her progress the vessel gets into water of gradually increasing specific gravity. At the Nore, the ports, instead of being exactly level with the water, will therefore be some inches above, presuming, of course, as we must do, that perfectly still water is experimented with.

On the other hand, if the same vessel be loaded at the Nore—that is, at sea—until the water reaches her ports, and she be towed up to London, she will gradually *sink* in the water, because, during each mile of her progress, she is getting into water of less specific gravity: and if she reach Gravesend, it would be well; but certainly her further progress would be stayed by her sinking, through the water entering her ports. For exactly similar reasons, a vessel that would just float in Thames water, near London, at low tide, would, if she were taken to the Clyde, near Glasgow, at once sink; because the Clyde water, at that point, has less

specific gravity than the fresh water of the Thames.

Again, a person who can scarcely float in any of our fresh waters, will find that he has much difficulty in sinking in sea-water, because the latter has so much greater specific gravity. And in the waters of the Dead Sea, the buoyancy is so great, that it is impossible for a person to sink, unless he be so determined; and even then suicide would become almost as difficult.

Therefore, in our illustrations, both the ship and the human body are hydrometers on the large scale, and precisely illustrate the principles on which the refined instrument of the practical chemist and of the distiller is constructed and employed for the purpose of taking specific gravities.

The hydrometers used in the spirit and other trades are of a more special character, and do not refer so much to the actual specific gravity as to certain arbitrary scales that have been long adopted as more convenient in practice, and better understood by the practical man. The leading kinds are Twaddell's, Beaumé's, and Sikes', all of which have been more or less modified to meet modern requirements or improvements. Occasionally the term alcoholometer is applied to such instrument; but, in the trade, the name of hydrometer is generally used. At times spirit-bubbles are employed, which are marked externally with a number that is equivalent to the degrees of Sikes' hydrometer indications, at a temperature of 60°.

Before describing any particular form of hydrometer, we must first state why a certain temperature is chosen as a standard. All bodies expand, in different degrees, generally, and amongst themselves, by the addition of heat. Solids expand least, but variably amongst themselves; gases expand most; and liquids occupy an intermediate place between the two. This fact is familiarly illustrated by the mercury or spirit of an ordinary thermometer, either of which expands by heat, and contracts by cold; hence, in fact, the indications of the instrument.

If, therefore, by way of comparing the specific gravity of one liquid with another, no attention be paid to the temperature, a great source of error would arise; and, in fact, the indications of the hydrometer would be valueless; and, indeed, still worse, they would lead to the most erroneous and ruinous conclusions in respect to the charge of duty by the excise; for if the exciseman were to take the gravity of the spirit at a high temperature, the distiller would greatly lose; whilst if he take it at a low temperature, the government would become, in a similar ratio, the loser. Thus 1,000 volumes of alcohol contract, by cooling, as follows:—

By cooling through	The contraction is
18° Fah.	11·43
36 ,,	24·34
54 ,,	34·74
72 ,,	45·68
90 ,,	56·02
108 ,,	65·96

In round numbers, water may be considered, on an average, as contracting to an extent equal, approximately, to half of the preceding values for the same degrees of temperature by Fahrenheit's thermometer, the error being in excess; that is, the actual contraction is somewhat less than one-half. Now as all spirituous liquids dealt with by the distiller and excise contain water, of course a kind of complex form of error is introduced, that can only be obviated by choosing a standard temperature. This is conveniently, in our climate, fixed at 60°; but, of course, as this cannot be secured at any moment in the year, reductions have to be made, by which any actual temperature may be brought up to that of 60° Fahrenheit. For this purpose, in using nearly every hydrometer, tables are referred to, that give this reduction to 60° for any required temperature, without any necessity for calculation. It is, of course, also obvious that an accurate thermometer is absolutely necessary as an accompaniment to the use of the hydrometer.

In describing the different kinds of hydrometers in use, we shall avail ourselves of a work by an esteemed friend, for about half a century known as a leading experimental chemist, and one that has done the greatest service in improving and simplifying philosophical apparatus; and, still better, perhaps, in respect to the progress of science, producing apparatus at such a price as will permit its pursuit by persons of the most limited means. The following explanatory observations on various hydrometers, especially those of an improved character, we are therefore indebted for to Mr. J. J. Griffin.*

In his improved form of Twaddell's hydrometer, the round bulb is replaced by a pear-shaped body; the advantages thus gained being greater sensibility, durability, and the power of taking the density of a smaller quantity of liquid than is required by the ordinary form.

In his description of its use, Mr. Griffin states as follows:—As the specific gravities of liquids are commonly denoted in books, in reference to hydrometers which indicate the direct specific gravity of liquids in comparison with that of water, taken as a standard, and denoted by 1000 [or 1·000], whilst manufacturers in this country are much in the habit of speaking of specific gravities in reference to the scale adopted by the late Mr. W. Twaddell, it may be useful to show the relation of degrees marked on *Twaddell's hydrometer*, to those which express the actual specific gravity of a liquid. The calculations are made by the following *formulæ*:—

Let a = any degree of Twaddell's hydrometer.

Let x = the specific gravity in relation to water, taken at 1·000.

Formula 1.—To convert Twaddell's degrees into specific gravity—

$$x = 1\cdot + (a \times \cdot 005).$$

Formula 2.—To convert specific gravity into degrees of Twaddell—

$$a = \frac{x - 1}{\cdot 005}$$

* *Chemical Handicraft;* by J. J. Griffin, F.C.S.

As examples of these *formulæ* take the following :—

Example 1.—If a liquid mark 5° of Twaddell, what is its specific gravity ?

By *formula* 1, the specific gravity is—

$$\text{Sp. gr.} = 1 + (5 \times \cdot005) = 1\cdot025.$$

Example 2.—If a liquid have the specific gravity of 1·850, what degree of Twaddell's will that indicate ?

By *formula* 2, Twaddell's is—

$$\text{Twad.} = \frac{1\cdot850 - 1}{\cdot005} = \frac{\cdot850}{\cdot005} = 170.$$

Hence 5° of Twaddell = the specific gravity of 1·025, water = 1·000.

And 170° of Twaddell = the specific gravity of 1·850.

To save calculation on the part of those who use Twaddell's hydrometer, the following table will be of much use :—

Table of Equivalent Specific Gravities and Degrees on Twaddell's Hydrometer.

Twaddell Degrees.	Specific Gravity. Water = 1·000.	Twaddell Degrees.	Specific Gravity. Water = 1·000.
0° . .	1000	110° . .	1550
10 . .	1050	120 . .	1600
20 . .	1100	130 . .	1650
30 . .	1150	140 . .	1700
40 . .	1200	150 . .	1750
50 . .	1250	160 . .	1800
60 . .	1300	170 . .	1850
70 . .	1350	180 . .	1900
80 . .	1400	190 . .	1950
90 . .	1450	200 . .	2000
100 . .	1500		

The specific gravities given in the second column are easily altered to the usual standard of water = 1·000, by putting the decimal point between the first digit on the left hand and the succeeding figure—as, for example, 1·000, 1·050, &c., &c. ; and as the difference for each degree of Twaddell, in reference to the standard of specific gravity, = ·005, any single degree of Twaddell is thus denoted :—

Twaddell.	Specific Gravity.	Twaddell.	Specific Gravity.
0° . .	1000	6° . .	1030
1 . .	1005	7 . .	1035
2 . .	1010	8 . .	1040
3 . .	1015	9 . .	1045
4 . .	1020	10 . .	1050
5 . .	1025	&c., &c.	

Another commonly used form of hydrometer is that of Beaumé's. The indications of this kind are readily reduced to the standard of specific gravity by the following formula :—

Let B = Beaumé's degree
,, 100 = water,

Then the specific gravity corresponding to Beaumé will be—

$$\text{Sp. gr.} = \frac{144}{144 - B}$$

That is to say—144 divided by 144 less the given degree of Beaumé, will give the specific gravity required, stated in relation to water estimated as 100.

Beaumé's scales are divided into two kinds—those for liquids heavier than water, and those for such as are lighter than water ; and the instrument-makers sell the two different classes in sets, with a thermometer separately. Mr. Griffin gives the following as the equivalent of degrees, Beaumé, to actual specific gravities, water = 1·000.

Scales of Beaumé for Heavy Liquids.

Beaumé's Degrees.	Actual Specific Gravity.	Beaumé's Degrees.	Actual Specific Gravity
0° . .	1·000	40° . .	1·385
5 . .	1·036	45 . .	1·454
10 . .	1·075	50 . .	1·532
15 . .	1·116	55 . .	1·618
20 . .	1·161	60 . .	1·714
25 . .	1·210	65 . .	1·823
30 . .	1·263	70 . .	1·946
35 . .	1·321	76 . .	2·118

The scale for liquids of less specific gravity than water, and commencing as the unit at 10° Beaumé, is as follows :—

Beaumé's Degrees.	Actual Specific Gravity.	Beaumé's Degrees.	Actual Specific Gravity.
10° . .	1·000	26° . .	0·892
12 . .	0·985	28 . .	0·880
14 . .	0·970	30 . .	0·871
16 . .	0·955	32 . .	0·856
18 . .	0·942	34 . .	0·847
20 . .	0·928	36 . .	0·837
22 . .	0·915	38 . .	0·827
24 . .	0·903	40 . .	0·817

It is much to be regretted that these artificial systems have replaced the more natural system of stating the actual specific gravity in relation to water. They have no advantage whatever in the present state of education, although, formerly, of course, they saved any possible chance of complexing the ideas of a workman in testing liquids ; and, consequently, have been perpetuated as a bad system from father to son. They are, therefore, as already hinted, more a matter of convenience, due to custom or habit, than founded on any principle whatever, except so far as they empirically express a relation to the actual specific gravities as denoted in relation to water.

The Board of Inland Revenue—which, by the way, we have irreverently called by the name of Excise ; but properly so, in fact, for the *excission* of its duties has been great of late years—have adopted Sikes' hydrometer for a long period. Its relationship of scale differs from all the preceding, because it only deals with, or indicates, the strength of spirits as "above" or "below proof"—terms already explained at p. 493, *ante*. The ordinary "Sikes," for estimating the commercial and duty-value of spirits, is generally a brass instrument, accompanied by a thermometer, a book of tables for reductions of temperature to 60° Fah., with general instruc-

tions, glass cylinder, &c.; and is, of course, as a matter of compulsion, of general use in the trade. It would be useless to describe to our practical readers an instrument of at least daily employment by them; but an improved form, after modifications by Mr. Stokes, deserves attention, for it is adapted for all temperatures, and saves much trouble in calculation and reference. Mr. Griffin describes it nearly in the following words, according to the form he proposes for trade use:—

Sikes' hydrometer, so modified by Stokes, has a glass spindle, with double scale, and accompanied by a thermometer. The degrees on the primary or black scale, represent per-centages of proof spirit, according to Sikes' brass hydrometer, used by the Board of Inland Revenue for testing the strength of spirit. The range of the glass hydrometer is from 40 below proof to 60 above proof (see *ante*, p. 493). The secondary or red scale, contrived by Mr. Stokes, provides a method of reducing observations made on spirit at any temperature, to the degree proper for the same temperature of 55°. The instrument is cheap, simple, and accurate; and, moreover (which are great advantages), requires no shifting weights, no sliding-scale, nor reference to a book of tables.

The directions for using it are as follow:—

"*When the spirit is* ABOVE *proof.*—Nearly fill a glass cylinder with the spirit to be tried; immerse the body of the hydrometer, and let it gently sink until it finds its resting-place. Then observe the degree marked on the red scale, corresponding with the surface of the liquor under trial, and not that which capillary attraction draws up round the spindle. Suppose the degree to be $37\frac{1}{4}$; write this number on a slip of paper. Then dip the thermometer into the spirit, to ascertain its temperature. Suppose it to be $2\frac{1}{4}$° below zero, or 0° [the zero of the thermometer accompanying the instrument corresponds with 55° Fahrenheit; each degree of the scale is equal to 4° Fahrenheit]; write this $2\frac{1}{4}$ on the slip of paper, below $37\frac{1}{4}$, and subtract the lower number from the upper; the remainder is 35. Look for this number on the red scale; and then, turning round the spindle, find what number on the black scale is on a line with 35 on the red scale. You will find it to be 19 *above proof.* This is the true strength of the spirit at 55° Fahrenheit, as would be indicated by Sikes' brass hydrometer.

"In all cases when the observed temperature is below 0, *subtract* the number of thermometric degrees from the degrees on the red scale; and, on the contrary, when the observed temperature is above 0, *add* the number of the thermometric degrees to the degrees on the red scale. In both cases the resulting number is one that stands on the red scale, level with a number on the black scale, which expresses the true degree of the spirit, above or below proof, according to Sikes, at the temperature of 55° Fah.

"*When the spirit is of* PROOF *strength.*—Suppose the degree shown by the red scale of the hydrometer to be $46\frac{1}{4}$, and the temperature to be $2\frac{3}{4}$° above 0. Write these numbers as before directed, and add them together. The product is 49. Opposite to this number on the red scale, the black scale shows P, which indicates that the spirit under trial is precisely of proof strength, according to Sikes, at 55° Fah.

"*When the spirit is under proof.*—Suppose the degree indicated by the red scale to be $62\frac{1}{2}$, and the thermometer to stand at 0. There is then nothing to add to, nor subtract from, the observed degree. You examine what degree on the black scale corresponds with $62\frac{1}{2}$ on the red scale. You will find it to be 20 *under proof*, which is the true strength of the spirit, according to Sikes, at 55° Fah."

The description which is thus given of this ingenious contrivance carries with it its own recommendation; for it is evident, that by the use of this instrument, not only are much time and trouble saved, but accurate results are afforded at the same time.

The spirit-bubbles, or beads, are a simple and effective contrivance for ascertaining the specific gravity of spirits, although less accurate than the preceding. The indication of the specific gravity is given by that bead which floats indifferently in any part of the spirit; for it is evident that then the specific gravity of each is equal. The following numbers of bubble correspond to the degrees of Sikes' hydrometer, named opposite to it, according to Mr. Griffin's list:—

No. of Bubble.	Per cent. or degree of Sikes' Hydrometer.	No. of Bubble.	Per cent. or degree of Sikes' Hydrometer.
16 .	45 over proof.	25 .	0 proof
17 .	40 ,,	26 .	5 under proof.
18 .	35 ,,	27 .	10 ,,
19 .	30 ,,	28 .	15 ,,
20 .	25 ,,	29 .	20 ,,
21 .	20 ,,	30 .	25 ,,
22 .	15 ,,	31 .	30 ,,
23 .	10 ,,	32 .	35 ,,
24 .	5 ,,	33 .	40 ,,

These beads may be conveniently used, not only with spirits, but with a large number of liquids produced or used generally, in chemistry applied to the arts and manufactures.

We have preferred to defer a description of the saccharometer to this part of the work, rather than to have mentioned it in connection with the sugar manufacture; because, by so doing, unnecessary repetition of the principles, and also illustrations of all four of the hydrometers, has thus been saved; and also on account of their application to the testing of the strength of spirits, which is of most importance. The saccharometer is at once applicable for ascertaining the strength of wort, and of showing the gravity, of which mention has been made at p. 485, *ante*, and at other pages, under the head of BREWING. In principle it in nowise differs from the instruments already described as adapted for Twaddell's, Beaumé's, &c. But a considerable variety of them have been offered for use. For England, saccharometers are graduated for a temperature of 62°; but if required for the West Indies, to test cane-juice or sugar in process of

manufacture, the graduation is effected in relation to a temperature of 84°, about the annual average of the climates there and in Ceylon. Sugar in solution ranges from 1·000 to 1·321 in specific gravity; water = 1·000; whilst the expressed juice, fresh from the cane, rarely exceeds 1·120. For the purpose of testing such solutions, Beaumé's hydrometer for heavy liquids (see *ante*, p. 496, for table), or Twaddell's hydrometer (see *ante*, p. 496), may be used. It will be unnecessary for us to give a description of all the different kinds that have been brought forward, as all our practical readers requiring their use, will get more valuable information from the instrument-makers, in respect to instruments best suited for their especial purpose.

We may conclude these remarks by some advice in respect to thermometers to be used in connection with the hydrometer. In certain instances these are specially graduated, as in the case of Sikes' hydrometer, modified by Stokes, already described at p. 497, *ante*. But generally a Fahrenheit's thermometer alone is required.

The only quality of value a thermometer can possess is that of being accurately graduated; and it is impossible to obtain such an article without paying a good price for it. The cheap thermometers exposed in shop-windows of our large towns, and warranted correct, are almost invariably incorrect; and a simple inspection of half-a-dozen, being side by side, will often be sufficient to prove the fact; for a difference of several degrees between the indications of each may be frequently noticed. Of course such instruments are worse than useless, as may at once be seen by reference to the table at p. 495, *ante*, which gives the rate of contraction that alcohol undergoes for certain diminished degrees of temperature from a normal point. The graduation of a thermometer depends on first fixing two points, which are, in respect to Fahrenheit (the only one used in this country), the freezing-point of water, or 32°, and its boiling-point, or 212°, both at the sea-level. Between these two extremes the thermometer is divided into 180 parts, by measuring equal divisions, called degrees, on the scale. Two sources of ordinary error may therefore arise—either the graduation is not of equal length for each degree, or the glass tube is of unequal bore. The former source of error can only occur in the commonest instruments; for no respectable dealer would disgrace himself by carelessness on this point, as it could bring him neither profit nor reputation. But, in respect to variations in the size of the bore, such may occur in even a good instrument, in consequence of the method of graduation just described being adopted, and that it sets out exactly equal measurements on the scale. But it must be remembered that the mercury in the thermometer expands in bulk necessarily, and, in length, only accidentally; that is, if placed in an open vessel, it would, if heated, expand in all directions; but, by the construction of the thermometer, it is forced, as it expands or contracts, to travel in a long narrow channel or tube.

If any part of the bore of this tube be narrower than another, the exact degree on the scale will be shorter than that which is indicated by the instrument, for the mercury at that part will expand to a greater extent, in *length*, than the alphabet measurement on the scale. On the other hand, if at any part of the tube the bore be larger than the average proper length, then the mercury at that will expand both in bulk and length; consequently, the scale-indication will be longer for each degree than the expansion indicated at that point by the mercury.

A simple method of detecting both errors is as follows:—Detach a small length of the mercury—say an inch—from the whole by gently tapping the thermometer. Then run this up and down the stem, measuring, by means of a pair of compasses, the number of degrees, and parts of a degree, equivalent to the length of the detached portion: if at all parts of the scale the length of this is equal, as indicated by the graduation, of course the bore of the tube must be of equal diameter throughout its length, and is, therefore, trustworthy.

Thermometers are specially constructed for brewing purposes, and generally have a cistern at the lower part, to hold the wort or other liquid. It is desirable to keep the cistern and every part as clean as possible; and that the whole should be carefully washed at the end of each trial, for reasons already assigned repeatedly in the preceding article on Brewing.

We have already previously noticed some of what we may call semi-civilised sources of intoxicating drinks—as the fermented mare's milk of the Tartar; the abominable drink of the South Sea Islanders; and the palm wine, or toddy, of hot climates. To them we may add the two following.

Fig. 366.—The Agave.

The *Agave Americana* is a plant known as the American aloe, and represented in the above

cut. It affords a juice that, on fermenting, produces an intoxicating liquor, called *pulque*, that is much used in Mexico. These plants, although largely cultivated for their juice, afford also valuable fibres. They require to be about five or six years of age before they give the juice. "The Mexicans cut the bundle of central leaves of the plant, and enlarge the wound, covering it with lateral leaves, which they raise by drawing them close, and tying them at the extremities. In this wound the juice seems to collect from the plant generally, forming a true vegetable spring, that keeps running for two or three months, and from which the cultivator draws three or four times a day. One plant commonly yields eight pints in twenty-four hours; and some have been known to yield seven quarts per day for four months. This juice contains a great deal of sugar and mucilage, and when allowed to ferment it produces the pulque—a vinous beverage, with an extremely disagreeable odour, but stomachic and nutritive. A very strong brandy is distilled from it. A species of palm, a native of the islands of the Indian Archipelago, the *Areng saccharifera* (represented in the following cut), produces a

Fig. 367.—The Areng Palm.

juice, or sap, that flows abundantly about the time the fruit is forming. A branch is cut off, and the sap is collected by means of a bamboo rod tied to the extremity. By fermentation, an intoxicating, astringent, and stomachic beverage is produced, and much esteemed by those accustomed to drink it; but, we believe, is not relished by those who are unhabituated to it, and so far resembles the *pulque*, previously described. It is thus evident that drinking customs are by no means confined to European civilisation.

WINE-MAKING.

The history of the growth of the vine, and of the manufacture of wine, dates, at least, from the time of Noah, and, doubtless, much sooner, as the liberal use he is related to have made of it, proves that, at that early period of the world's history, an indulgence in strong drinks must have become common. From that period to the present day, wine, as a beverage, has been characteristic of all civilised or partially civilised nations. Greeks, Romans, and, indeed, nearly every other nation of Europe, identify wine with ideas of pleasure and luxury. Indeed, it is a question whether the Romans of twenty centuries ago, were not as great epicures in wine-drinking, as Great Britain, France, Germany, &c., are at the present day. Whatever, therefore, may be urged against the use of wine as a beverage, it is to be feared that the perpetuation of a practice for five thousand years; its traditional handing down from generation to generation, as an art in making; and the great revenue that most nations derive, either from its manufacture or fiscal regulations in respect to its import, export, and sale—all these will form a strong wall of defence, that the most vigorously-urged battering-ram of argument will take long to cast down.

In taste, chemical character, and mode of production, wine essentially differs from beers and spirits, not excluding even brandy, which is produced by the distillation of wine; for that spirit has no more special flavour of a wine character than has whiskey at first distillation. Wine partly owes its flavour, or *bouquet*, as it is technically termed, to the presence of an ether, called *œnanthic*, or *wine ether*, which belongs to the same category of ethers already described at p. 493, *ante*, when we pointed out how fusel oil could be made available as a source of some of the most perfect imitations of the flavour of the pear, &c., as rancid butter, by its butyric acid, can be used to give the flavour of the pine-apple, &c. When wine is submitted to distillation in a proper manner, its ether can be obtained as a mobile, colourless liquid, having a strong smell of wine, readily soluble in alcohol; and, which is a remarkable exception to all ethers, its boiling-point is very high—namely, about 480° Fahrenheit.

In one respect, certainly, wines agree, in constitution, with malt liquors and spirits; for they all contain alcohol. The strongest London porter generally has but 3 per cent.; stout from 4 to 5; ales from 4 to 8; Spanish wines, 18 to 25: French wines are very various in respect to their alcoholic per-centage; but this is less than in those of Spain; whilst gin, rum, brandy, whiskey, &c., run from 30 to 50 per cent. in respect to the possession of alcohol of a specific gravity of 0·825 (see *ante*, p. 493). It is hence evident that wines of all kinds take an intermediate position in respect to the quantity of alcohol they contain, as compared with beers and spirituous liquors.

In a certain respect, malt liquors and wines

agree; that is, the first always, and the latter occasionally (as in sparkling wines), contain carbonic acid gas. It is a remarkable fact, that whilst this gas is so deadly in its effects as taken into the lungs, it has a most beneficial action when taken on the stomach. It is familiarly known how refreshing a glass of soda-water, lemonade, ale or porter, champagne and other sparkling wines, is to the palate and stomach. To the healthy man, a draught of any of these at once revives vital action after long fatigue, not from the alcohol they contain, because the effect of re-invigoration is all but instantaneous, and occurs long before the alcohol has had time to affect the brain. The result that we allude to entirely arises from the action of the carbonic acid on the *papillæ* of the tongue, and the velvet-like, minute covering of the stomach, which instantly arouses nervous action, and spreads a kind of electric influence over the whole body. But to the invalid these sparkling drinks are of still greater value. At one time, brandy, sherry, and other strong wines were administered as restoratives in the early and later, or even the last stages of exhaustion; and, doubtless, proved of value. But such beverages as contain compressed carbonic acid are of much greater efficacy. Many years ago, whilst attending the death-bed, as it was supposed, of an aged relation, who had been "given up" by his medical attendant, and to whom the usual large quantities of wine and spirits had been administered without effect, it occurred to us to try a little champagne. Scarcely swallowed with great difficulty, its effect was instantaneous; exhausted nature revived at once; and repeating this dose at intervals, the inaction of the stomach was gradually overcome, and the "death-bed" was postponed for at least ten years. At all our hospitals this fact is now in constant and hourly recognition; and sparkling wine forms an important item, as a remedial measure, in cases of great nervous and physical exhaustion.

It is therefore evident that, apart from their alcoholic nature or qualities, certain wines, from the possession of condensed carbonic acid, produce beneficial effects on the system; and hence, as just mentioned, arises one point of similarity to malt liquors, which are undrinkable without that quality. "Spirits," on the other hand, as gin, brandy, rum, &c., cannot possibly possess carbonic acid; and hence the only power of stimulating they possess, is due alone to the alcohol they contain. It is thus found that persons addicted to their use, or to that of the heavy brandied wines of Spain, such as port and sherry, constantly desire a gradually increasing quantity. That which, a few months previously, produced sufficient stimulus on the brain and nervous system (or the stomach, as the medium of communication to both), has lost its power, and either increased quantities, or greater strength in the same quantity of spirit, is required, and taken. A *crescendo* scale of the spirit-drinker may be made by commencing with gin, going on to whiskey, rum, brandy, spirits of wine, and ending, if the indulgence be continued, in liver-complaint, the lunatic asylum, the workhouse, and, last scene of all, the maniac's death from *delirium tremens*—a sight that, once seen, would act as a warning, that none but the most hardened would venture to run the risk of repeating in themselves. So inveterate does the habit become, that although methylated spirits, permitted to be used in place of spirits of wine, are purposely mixed with naphtha-spirit, to render them abominably offensive to the palate—yet a determined drinker will even have recourse to them; and on one occasion we were requested to see a man who had arrived at entire insensibility through drinking French polish diluted with the methylated finish.

In respect to the saline constitution of wines, we also perceive a great difference from malt liquors. Of course, spirits contain no saline matter; whilst all forms of ale and beer have more or less of the mineral constituents of the grain from which they are made, such as phosphate of lime, carbonates of potash, lime, magnesia, &c. The great characteristic salt of wine is the bitartrate of potash, familiarly known as *Tartar* and *Argol* in commerce. It is a combinafion of tartaric acid and potash, the acid being in excess. In medicine, when purified, this salt is sold as *Cream of Tartar*, and it is the source of the tartaric acid of commerce. It is deposited on the bottom and sides of casks containing the juice of the grape undergoing fermentation; and its importance may be imagined when we state, that the annual import of the unrefined article as argol is, at least, thousands of tons annually.

Besides the above salt, wines contain malic and tannic acid, and, perhaps, citric acid; a double tartrate of alumina and lime; malate of lime, phosphate, and carbonate of lime; and salts of magnesia, iron, and manganese. As a rule, red wines contain more saline matter than white; and the deposition of the "crust" of port wine amply illustrates this fact to the connoisseur of that article.

The organic constituents of the grape are, in one respect, peculiar. In regard to wine-making, the grape sugar (see *ante*, p. 470) is of the utmost importance; for, as there shown, it is the source of all alcohol in wines, beers, and spirits. But in the grape, as in many other fruits, it exists ready formed; whereas, in malt, it has to be produced by malting—a process already described, in its scientific and practical details, in a preceding and separate article. But another characteristic of the juice of the grape, is the possession of a nitrogenous or albuminous principle, which has the power of inducing spontaneous fermentation without the addition of yeast, as is necessary for the fermentation of a solution of malt sugar or wort, as fully described at p. 484, *ante*, in respect to brewing. The grape also contains a colouring matter, to the presence of which the colour, greater or less, of the wine is due; resinous and waxy matter; mucilage, or gum, &c. These are the most important organic constituents of the grape and its juice.

In some wines, a peculiar form of ether, besides the *œnanthic* (already described), exists, and hence the flavour distinguishing one kind from another. The effect of this may be called the *special bouquet* of any individual wine. Thus, Rhenish wines are specially distinguished from others by that *bouquet*. As part cause of these varieties of flavour, besides œnanthic ether, are the butyric, valerianic, and acetic ethers, with others that have as yet eluded the grasp of the chemist.

Colour is another property distinguishing wine ; and this depends on the colour of the grapes employed to produce the wine, which varies from "white," or, more properly, light-green, to dark purple. There is no doubt but that the amount of free acid in wines affects greatly the colour, for all vegetable colours are affected by acid—blue being turned red ; whilst alkalies restore that red to blue or purple, if the red had been previously caused by acid. Now most wines contain the acid tartrate of potash, besides a certain amount of free acid. It is considered that the grape contains most of the bitartrate of potash just before ripening, and that a portion of it disappears as the grapes attain their full maturity. It is remarkable, that whilst all our native fruits are deficient in tartar, although possessing other salts, the addition of tartar in making British wines is of considerable advantage. Malic acid, whilst abundant in fruits of our island, is generally present in small quantities in the grape. "It is remarked, that all those wines which contain much malic acid are of a bad quality, although it is not well ascertained, by chemical trials, whether this acid is a constituent of bad varieties of grapes, or whether it is generated during the conversion of the other constituent matters into wine. It is sufficient, for practical purposes, to know that its existence in excess is injurious to wine. It is important to attend to this distinction, as our native [British] fruits are all characterised by the excess of malic acid, which appears to be the acid predominant in them, and to which their qualities are owing. It is, perhaps, mainly to this cause that we are to look for the defects which seem almost necessarily inherent in our native wines—defects which we possibly have no means of obviating. To render this matter more clear, it must be observed, that the leading distinction between wine and cider consists in the great predominance of malic acid in the latter, and that this cause invariably leads our native wines to partake of the properties of cider, unless when these are disguised, rather than changed, by the quantity of sugar and other foreign matter added to the juice of the fruit before fermentation. * * * * In the manufacture of sherry, lime is added to the grapes—a circumstance apparently conducive to its well-known dry quality ; and which, probably, acts by neutralising either a portion of malic acid contained in them, or a part of the tartaric acid."*

Having thus stated some of the chief points of difference that subsist between wine made from the grape, and the alcoholic products of corn—as beer, spirits, our native or "British wines," &c.—we proceed to detail a few particulars in respect to the vine and its fruit, the grape.

* Macculloch.

The vine, in the natural system of botany, forms a distinct order, called *Ampelideæ*. The most important genus and species is the Grape-vine, *Vitis vinifera*, which may be taken as a type of the order. All the species are climbing, jointed shrubs, readily trained into almost any form ; often with abortive flowering branches, serving as tendrils, by which the plant clings by its branches to others for support. None of the order are native in Europe, but have been chiefly derived from the East Indies. "The grape-vine, now cultivated so extensively in France, Germany, South Europe, the Atlantic Islands, United States, the Cape, Australia, &c., was, very probably, native originally of Western Asia, and to the south of the Caspian. From its innumerable varieties, affected by different climates and soils, we have, besides grapes yielding the various wines of commerce, other sorts, which are dried, forming Valentia, Muscatel, and Sultana (without seeds, and from Turkey) raisins ; also currants, the dried fruit of a small-fruited variety of the grape-vine (*Vitis vinifera*, of the variety *Corinthiaca*), cultivated in the Ionian Islands, Greece, the Lipari, &c." The latter are the "currants" sold at our grocers' shops, and are entirely distinct from the garden currant grown in this country : this belongs to the genus *Ribes*, which is allied to the Gooseberry order. It would be impossible for us to enter into any description of the various countries that are now wine-producing. In our country the climate is too cold and uncertain to admit of the culture of the grape for the purpose of making wine ; as although, as a dessert, some splendid specimens are reared in our public and private gardens, in hothouses, still our best productions fall infinitely short of the luxuriance that the vineries of Spain and Portugal present when the vine, trained over a trellis-work three feet high, is loaded with bunches of such a length as almost to touch the ground—this kind being that which is used for wine-making.

France produces several varieties of wines : but before the removal of our fiscal duties, their importation for sale here, except at high prices, was comparatively small. The effect of this prudent step on the part of our government was such, that whilst, in 1859, the total quantity of French wine imported amounted only to about 700,000 gallons, two years afterwards the importation was trebled ; and since that period the same beneficial result has been progressing. Amongst the leading French wines, are Claret, of which there are numerous varieties, according to the places of growth, or called after the growers ; Barsac, Vin de Graves, Sauterne, Chateau Yquem, and Chablis, all of which are white wines ; various kinds of Burgundy, and an equal variety of Champagne.

From Spain and Portugal we receive, respectively, sherry, named after Xeres, in the vineyards near which that wine is largely pro-

duced; and from the banks of the Douro, in Portugal, the favourite port is procured. Lisbon and Bucellas are white Portugal wines. The most important of German wines are still and sparkling Hocks; amongst the latter of which may be specially named, the celebrated Hochheimer, Rudesheimer, and Johannesberger—so called from the vineyards supplying these celebrated wines; still and sparkling Moselle, &c., &c. Besides these, are Madeira; Sicilian wines, including Marsala, &c.; South African wines, respectively called after sherry, port, Madeira, &c.; and Hungarian wines, which include the celebrated Tokay. Italy and Greece also produce varieties; and other countries are making rapid progress in the growth of the grape, and the production of wine.

The following remarks, for which we are indebted to an eminent judge of wines, will be read with interest, as descriptive of some that have been, comparatively speaking, only recently produced for export from the countries growing them:—

"Much as South African wines have suffered in popularity from prejudiced drinkers, we doubt not they will take a place amongst popular vintages.

"The principal vineyards at the Cape are situated in the vicinity of the capital, where the beauty of the climate, and the equality of the temperature, are unquestionably favourable to vine culture. But the proper choice of a site for a vinery was seldom taken into consideration by the Dutch, who first commenced planting under the governorship of Von Riebeck, in 1650. The fertility of some ground near the early settlements was great; yet not on that account alone more adapted for raising the vine; plantations were, nevertheless, formed in ineligible spots very soon after the settlers began to take up the land.

"The wines of South Africa comprise both red and white varieties, the large portion being dry. Besides the delicious and highly-prized Constantia, other excellent wines are made at Paarl, as well as at Drakenstein and Stellenbosh. The fruit is rich, full, and large, leaving none of the earthy taint formerly considered a characteristic of the wine. It is not impossible, therefore, that this peculiarity was derived from the stalk and stems; for all usually went into the vat together, the whole management being formerly confided to negroes; but now the better methods of culture, and the application of more care, skill, and system in the process of manufacture, afford honest reason for believing that, for vinous excellence and ability, they equal many high-class continental wines, and are superior to most of the secondary growths of either Spain or Portugal.

"One of the most important new markets for wine ought to be found in Italy, if that long-suffering, but now nearly free country, will only take advantage of its great natural resources. The production of wine, after its agriculture, is the most important work on Italian ground. Nature has given the Italians every encouragement to cultivate this trade; but, before 1861, the quantity of wine made in Italy had been very small, while the stock of old wines had dwindled to almost nothing: 1861, however, brought a plentiful vintage, and these are the wines that have been since imported into England. Young as they are, they form a pleasant drink. They are stout, compared to claret, and dry; some of the better qualities, such as Barbera, are still too rough for the English palate; but this peculiarity will disappear with time. The Barolo, Grignolino, and Monteferrato are fine stout red wines of Piedmont, more resembling Burgundy than claret, and which, when the vintage of 1861 is mature, will, probably, become well known in England. The sparkling Vino d'Astri (the Italian champagne), when genuine, is very delicious. Improved treatment of the vines, and great care in the process of manufacture, will doutless follow, if a constant demand arises in England.

"The wines of Hungary constitute another rich source of supply; and it is highly gratifying to record the almost unanimous approval they have elicited since their first importation in 1860, which was effected by the European and Colonial Wine Company. From political and other causes, the growths of this region have heretofore made but little progress in Western Europe, yet the various properties are of a high order; and they are further enriched by the presence of abundant phosphates, that enter, but especially the phosphate of lime, into the economy of the human system. These wines, after a careful analysis, have received the unqualified commendation of Liebig, as containing 'a peculiar restorative virtue, attributable to the phosphoric acid which they contain.'

"In the southern provinces of Russia, the vine, of late years, has been cultivated with considerable success. At Astracan, and in the Crimea, there are several hundred vineyards, yielding a red wine of good quality. The plantations here are very old; and the grapes, which were first introduced from Persia by a priest, in the fourteenth century, have been long noted for their size and flavour. Both red and white wines are produced in Astracan, where twenty different sorts of wine are cultivated."

A new, cheap, and wholesome wine was first introduced into this country at the Exhibition of 1862, held in London, by the company already named. It is called Beaujolais, and is produced in the valley of the Rhone. It has a full body, and rich flavour; and has been highly recommended for medicinal purposes, besides having since become generally popular.

In the Exhibition of 1862, we were particularly struck with the great variety of wines exhibited by Austria, and came to the conclusion, that, at some future day, that country, but especially Hungary, would arrive at a notoriety equal to many other continental countries, whose wines are now so popular, and so largely imported. Our Australian colonies have also taken up the production of wine; and although, at present, no great commercial result has followed, still much may be expected from that source.

It is much to be regretted that no really good analysis has yet been made of soil in which any sort of vine grows best, in regard to the production of a grape that affords the best classes of wine; and we have searched in vain for information that could be of any real scientific value.

From the general nature of the soil of Spain and Portugal, and their geological characteristics, it would seem that calcareous loamy soils are those which best suit the vine in those countries, and others where the grape best flourishes. It has long been our opinion, founded on some extended conversation with growers, importers, and others, that the presence of sulphur, in some form, is desirable; and it is a remarkable fact, that countries partly of volcanic origin are generally those in which the vine grows best. But it would be most unphilosophical on our part to insist on any value in respect to the opinion thus offered. We simply suggest it for the consideration of those who may be able to put the question to an experimental investigation. It is only by such means, and by extending the observations for a series of years, that any satisfactory conclusion can be arrived at. It certainly seems to us, that the vine-culture of the present day is generally as little understood, in relation to scientific principles, however much experience may guide the grower, as agriculture was, fifty years ago, in England, in regard to its chemical and scientific aspects generally. Whilst penning these lines, we have with us a gentleman who has travelled over every wine country in Europe, and purchased their wines; who is esteemed, in the London trade, as one of the best judges, but who still is quite unable, after an experience of nearly half a century, to point out a general series of causes, obedience to the influence of which success in wine-growing may be expected. We cannot help expressing the opinion, that a Liebig is as much required in wine-culture as he has been in agriculture; and we shall hail, with pleasure, the advent of such an individual, who, practically acquainted with the growing of wines, shall also be enabled to apply successfully, or teach the application of some scientific doctrine, in respect to the culture of the vine.

Having thus drawn attention to the chief varieties of the vine, its grape, the wine produced therefrom, and the chief countries of its production, we next turn to consider the practical part of our subject.

The grapes are generally plucked as soon as they are perfectly ripe, for, at that period, they contain the largest amount of available grape sugar for fermentation. About the middle of September is the period of plucking in the sherry districts of Spain; but, of course, the exact time will vary with the season and other causes. It is customary, in some parts, to expose the grapes to the action of the sun for a day or two, turning them, so that every bunch and part of a bunch is exposed to its rays.

The next step is that of pressing the juice from the grape; and the process has but slightly varied from the earliest history of the grape. In the Scriptures we frequently find allusion made to treading the wine-press, indicating that, at various periods, men were employed to compress the fruit by the feet. This method was adopted, and still is, to a small extent, in Eastern countries; and even until recently, a cart filled with grapes, with buckets at its side to receive the juice, and men pressing that out of the grape by the feet, was adopted in some portions of Austria.

Of course, in all large wine-producing countries, some form of machinery has been introduced. The wine-press, as used in the sherry districts of Spain, is generally a square trough a few feet each way, and sixteen inches deep; this holds the grapes, and the juice of them is pressed out by forcing down a kind of cover into the trough, by means of a screw and lever. "A large quantity of grapes being heaped up on one part of the trough, the labourers commence by strewing upon them a little powdered gypsum (sulphate of lime). Some of the grapes are then spread over the bottom of the remainder of the trough, upon which the men jump with great violence, having heavy wooden shoes on their feet. The grapes being then piled up round the screw, the press is worked, and the 'must,' or juice, flows out abundantly. The bottom of each trough is elevated two or three feet above the floor of the cellar, with two or three spouts so arranged as to allow the must to fall into vessels beneath. The must is then poured into butts, and the skins and husks, after having had water added to them, are again pressed to yield an inferior quality of must." The juice having thus been obtained, next requires fermentation; and, as already explained, it contains a substance that is capable of producing spontaneous fermentation. Gradually the grape sugar is converted into alcohol; and, if for still wines, the fermentation is carried as far as possible short of producing acidity. But in sparkling wines, such as Champagne, Moselle, and Hock, the fermentation is not completed, for it is left to act still further after the wine has been bottled, and thus carbonic acid is forced into the wine by its own pressure, as given off, resulting, of course, in the escape of the gas when the wine is drawn, and of the production of an effervescence characteristic of those kinds of wine, allusion to which has already been made at p. 500, *ante*.

The period at which the fermentation is complete, of course varies, in different wines, with the temperature of the atmosphere, and from other causes; and all these circumstances call for the exercise of judgment on the part of the grower. The addition of brandy, and other methods of making the wine fit for the market, are equally matters that require great care and discrimination.

When ready, and sufficiently fermented, the wine thus procured is conveyed to large casks, which receive yearly additions of each vintage; so that, in certain cases, there is, possibly, wine in a vat, scores, if not a hundred years old. But great judgment is required in this matter; for the value of the vintages varies so greatly

with the seasons, the presence of disease called *oidium*, and from other causes, that it frequently happens, if the wine-merchant can guarantee an article of a certain year's vintage, he may command fabulous prices—from a guinea upwards per bottle ; such wines being often denominated "curious old wine, of vintage 18—," as the year of its production may be.

A large proportion of the wines of foreign countries are imported in the cask into this country, and, on arrival, are stored in bond ; that is, they are deposited in a bonded warehouse until the merchant, or private purchaser, chooses to pay the duty, and remove the wine to his own private cellar. This is almost invariably the case with Spanish wines, such as sherry and port, and also with others that need not be detailed. Continental wines, on the other hand, from their lightness, and containing, comparatively, much less alcohol, would be utterly unfit for drinking if so imported. They are, accordingly, bottled before being exported ; and, in that condition, reach the consumer in other countries.

The following instructions in reference to the treatment of wines by the consumer, may not be without their value to many of our readers. We have received them from an authority already quoted, in our remarks on new wines, at p. 502, *ante*, and we give them without alteration.

"Wines kept long in bond should be periodically examined, as, perhaps, a defect in the cask might arise, which would call for the aid of a cooper.

"Most wines, but port especially, require to be racked from the lees occasionally ; and, if young and full-bodied, should remain in wood from five to six years before bottling. A good sound vintage wine will be found sufficiently matured, and fit for table, after ten years' repose in *wood;* but if kept the same time in bottle, *under judicious management*, it will be found in as good condition as any one need desire ; and will not materially improve, *except in cost*, if kept for fifty years.

"All red wines should be fined with the white of eggs ; eight to the pipe, or five to the hogshead, is the requisite quantity. Claret should be fined at *full moon*, and turned half-bung downwards, to prevent the admission of air. The proper fining for white wines is *pure* isinglass, an ounce of which must be dissolved in four quarts of water, with a small teaspoonful of citric acid. Two quarts of this mixture is the necessary quantity. Red wines may be bottled in about six weeks after fining ; and white in about two months. Old bottles are the best for bottling ports ; for, being seasoned, the wine will crust better in them.

"The temperature of the cellar should be about 60° Fah. ; and, in winter, especial care should be taken not to admit cold air. If the cellar, therefore, be in an exposed place, a blanket may be hung over the doorway with advantage.

"Claret should never be iced, or it will entirely lose its flavour and *bouquet*. In winter, after the cork is drawn, it may be placed near the fire, for about five minutes, before decanting ; but such is the delicate nature of this wine, that its beauty is far better developed when drunk from the original bottle.

"Claret and champagne should always be kept in an horizontal position.

"All South African wines, both red and white, are greatly affected by frost ; and, if so exposed, will entirely lose their brilliancy. But *if properly treated*, they will be found as agreeable and wholesome as any wines shipped to this country, and certainly by far the most economical wines ever introduced.

"It should be borne in mind, as a general rule, that warmth hastens the ripening of wine, whilst cold retards it."

The extent of the wine trade is, of course, very great ; and as such, it tempts a large number of persons to embark capital in the growth of the wine, in its manufacture, export, and retail sale. It is much to be regretted that all these circumstances continue to render it very difficult to obtain what is only humbly called a "decent glass of wine." The substitute of an inferior wine for one of a superior kind is so common, as to be almost legalised by the public at large ; or, at all events, if not legalised by consent, it is suffered by necessity and custom. An amusing instance of the kind is as follows :—An extensive wine-merchant in London invited a number of his best friends and customers to dine with him, at a town on the banks of the Thames, about twelve or fourteen miles west from London ; the place being equally noted for the number and expensive character of its hotels, almost exclusively devoted to the entertainment of gentlemen fond of dining in the country. Whilst at dinner, the merchant asked the waiter to bring up a bottle of Marsala. After a lengthened sojourn down-stairs, the latter worthy returned, with strong protestations of sorrow that they did not keep such low-priced wines on the premises ; albeit the wine-merchant had sent to the very hotel, during the previous week, a large quantity of Marsala in the cask ; and had every reason to believe that he was sipping that wine, which cost the landlord scarcely 2*s*. a bottle, although the merchant, in his hotel bill, would be charged 7*s*. 6*d*. for the same article, as "fine pale sherry."

It would be well, however, if substitution was the only evil that the consumer of wines is subjected to ; for, like porter and other malt liquors, spirits, &c., wine is subject to an almost endless series of adulterations. Colour is produced by logwood, and other red colour-giving substances ; the roughness of port is aided by sloe-juice ; want of spirit, or intoxicating power, is remedied by the addition of brandy, to any extent required. In fact, the low-class port and other wines sold in our cities and towns generally, are often a compound imitation of, but containing little or no wine. Sugar of lead is a common addition to some wines, to correct acidity, and give a sweetness of flavour ; and it is impossible to conceive a more villanous adulteration than this. It is almost certain to produce colic, and, pos-

sibly, might cause death; for, of course, whilst a strong constitution could withstand its effects, and get over them, a person of weak frame would be very likely to succumb to the poison. Several years ago we were requested to analyse a bottle of wine that had caused immediate illness to four gentlemen who had partaken of it after dinner at an hotel. It was literally charged with the acetate or sugar of lead; and had a "one-bottle" man taken the whole, his wine-drinking career would have been speedily closed.

The trade, again, is one of considerable uncertainty, owing to the variety of seasons, the disease to which vines are subject, and numerous other causes that we cannot here detail. It frequently happens, in such seasons, that the demand increases rather than decreases, and, consequently, great temptation is offered to fraudulent manufacture or adulteration. In all trades caution is requisite for the purchaser; but in respect to wine, the maxim *caveat emptor* is especially applicable. It unfortunately happens that nearly every person conceives himself to be a judge of wines, and, as such, lays himself open to being taken in. Still the trade can boast of men of the utmost probity, devoted to science, and philanthropic virtues; hence it must not be supposed by any means to be below any other of similar extent, and as furnishing an almost natural want of man. The restrictions that were formerly imposed by our custom dues having been so greatly modified, has opened out numerous new sources of supply, and hence a wholesome competition between producers, merchants, and retailers has been induced, the results of which cannot be otherwise than beneficial alike to the pockets and constitution of the consumers.

Testing Wines.—At p. 495, and subsequent pages, we gave ample instructions as to methods adopted in ascertaining the strength of spirituous liquors *before* rectification; but also remarked that, after that process had been effected, the hydrometer ceased to be of the least value if sugar-flavours, &c., had been added to the spirits; because all such additions have the effect of increasing the specific gravity, and, consequently, would make a strong spirit apparently much weaker than it really is. Now, wines contain not only sugar, but also salts in solution, that still further tend to raise the gravity much higher than that which the quantity of absolute alcohol present would indicate. As duty is charged on the alcoholic strength of the wine, rather than on its bulk, it becomes necessary to estimate the amount of spirit present by means other than the hydrometer; or, more correctly, so to separate the spirit that it may be correctly estimated. This can be done by first distilling a certain quantity of the wine, to be tested in a glass retort, by which all the alcohol may be drawn over, whilst the sugar, salts, &c., are left in the retort. The hydrometer of any kind already described at pp. *ante*, 494, *et seq.*, can be then employed to ascertain the specific gravity of the alcohol and water thus obtained from the wine by distillation; and the per-centage present in the quantity of wine operated on, is easily calculated by means of the tables given at the pages just referred to. The proportion of spirit in a gallon will, of course, be easily ascertained by noticing what proportion of that quantity has been operated on, and multiplying the quantity of alcohol so discovered by the number of parts that the experimental proportion bears to the gallon. For example, if ten ounces of the wine afford one ounce of proof spirit, then the latter is present to the extent of 10 per cent. Again, ten ounces avoirdupois is equal, in weight, to the sixteenth part of a gallon; twenty ounces, or 8,750 grains avoirdupois, being equal to one imperial pint, or the eighth part of a gallon. Hence, as the ten ounces are equal to the sixteenth part of a gallon, it follows that one gallon of the wine supposed to be under examination, contains sixteen ounces of proof spirit.

The detection of the amount of salts, acid, sugar, &c., present, can only be satisfactorily or accurately determined by careful analysis, for which the services of a professional chemist will be requisite.

It is usual to give tables of the per-centages which wines in general use possess of alcohol or proof spirit; but having examined many that have been published, and bearing in mind, also, that a large proportion of wines imported into this country are "brandied," it will be evident that analyses at different seasons, and of different vintages, must give results highly discordant with each other, even for the same wine. Most of our readers will see the force of these remarks from the results of their own experience, especially in regard to port wine, the per-centage of spirit in which is constantly varied, according to the views of the grower or importer. Visitors to the bonded wine-stores of the metropolis, and other large ports in England, will, if they carefully use their eyes, find that the process of wine manufacture has not ended at the port or vineyard whence it came; but is continued in our country, by the aid of brandy and colouring matter, to a very large extent. Hence, as already remarked, much more port and other wine is drunk in these islands than had been imported into them. Some years ago, we purchased a quarter cask of "port" from the docks, that had not a vestige of port wine in it, and which had never, as wine, been produced in any vineyard or vintage. We have already, however, gone into the question of adulteration generally; and shall only add, that we cannot offer any table that can be relied on, as giving an average per-centage of spirits in different kinds of wines. Those by Davy are decidedly inaccurate; and others have scarcely a greater amount of correctness, so far as we have seen and tested.

British Wines, Cider, Perry, &c.—There is no fruit in our islands that can be made to produce any liquor that deserves to be called wine, although such, as elder-berry, currant, gooseberry, &c., &c., are sold and drunk under that denomination. On this point, the following remarks from Mr. Macculloch's work on *The*

Art of Making Wine, in which he chiefly treats on the improvement of our domestic wines, will be perused with advantage :—

"It is a prejudice not uncommon, that the wines made from the fruits of this country are very unwholesome. There is no doubt that they may, occasionally, disagree with individuals, either from defects in their fabrication, from their undergoing the process of decomposition, from pernicious accidental admixtures, or from the idiosyncrasies of particular constitutions. But they are not necessarily unwholesome ; nor is any reason to be assigned, either from their chemical qualities, or from medical considerations, why they should produce effects more injurious than wines prepared from the grape. Occasional derangements of the *prima via* will not be considered, by physicians, as any proof of the general insalubrity of these wines; and their effects, whatever they are, will certainly be diminished by every step which they shall make in their approach to the wine of grapes—that standard of perfection to which they must all, ultimately, be referred.

"In alluding to the superiority which care, and a management conducted upon principle, will inevitably confer upon our domestic wines, when contrasted with the results of ignorant recipes, and loose practice, I am far from meaning to insinuate, that we can, by any mode of managing our native fruits, ever hope to imitate those foreign wines which are the produce of the grape. Nor is this the legitimate object of the art. Fraudulent vintners have undoubtedly attempted these imitations at all times ; but with the success of which all those who have tasted their wines are easily able to judge. Thus a wretched compound of common sugar-wine, with the juice of barberries and blackberries, is passed for claret, tartar and the colouring matter of logwood, or Brazil-wood, being added to the mixture. Thus, also, the admixture of sloes and blackberries with the same fundamental material, produces 'port,' the colour being derived either from the above-named dyeing woods, or from elder-berries. And again, Frontignac is imitated by elder-flowers and the inspissated juice of white currants. But it would be tiresome to enumerate the catalogue of nauseous contrivances which are practised in the fabrication of these pretended foreign wines. The circumstances in which our native fruits differ from the grape are so important and essential, that no legitimate hopes can ever be entertained of producing from them a similar liquor, much less a liquor equal in quality. Yet we can fairly hope to make a palatable, as well as wholesome, variety of beverages from them ; a class of liquors as various, at least, among themselves, as are the fruits from whence they are produced, and holding a sort of intermediate rank between our most natural wines—cider and perry—and that first of all liquors, the wine of the grape."

The preceding remarks are characterised by judicious caution ; and we have little doubt but that one conclusion therein arrived at will meet the approval of all our readers : it is, the impossibility of our ever hoping to make a beverage from native fruits approximating to the character of foreign wines. They all have an acidity, due to the presence, chiefly, of malic acid (see *ante*, p. 501), which has to be disguised, or covered, by large additions of sugar. The latter tends, on being taken into the system, to be converted into lactic acid, or the acid of milk, which, *in moderation*, is assistive of digestion ; but, *in excess*, is of the reverse effect, and tends to produce acidity of the stomach, and other inconveniences. Hence a great objection to the use of all "British wines," not excluding even cider and perry.

Two points—astringency, as found in port wine, and flavour generally, in all wines—are thus remarked on by the author just quoted :—

"With the exception of the elder-berry and the black cherry, scarcely any colour is contained in the fruits of this climate. But as this may be considered in the light of a mere ornament, and may be communicated by a variety of adventitious ingredients, it is unnecessary to say much respecting it. The essential and difficult parts of the operation in nowise depend on it.

"The tanning principle is known to be contained both in the husks and the stems of certain grapes; and it communicates to the liquor, at the pleasure of the operator, that roughness well known in port wines. Of our fruits it is possessed by the sloe and damson. It may be given at any time by the addition of kino or catechu ; but as it seems to be a quality by no means desirable, it is sufficient merely to notice it, considering, as I have done, the imitation of foreign wines to be an attempt which, if not illegitimate, is at least always fruitless.

"The other principle, that of flavour, is of a nature so uncertain and fugacious, that it is difficult to establish any general rules respecting it. In many grapes, as the Frontignan and Muscat, the flavour of the fruit is absolutely identical with that of the wine ; but, in these cases, the wine itself is always sweet, and but half fermented. The finer flavours of the best wines (those of Claret, Hermitage, and Burgundy) bear no resemblance to the natural flavour of the fruit, but are the produce of the vinous process. To many, a flavour is communicated by the introduction of flavouring ingredients, such as orris-root, grape-flowers, mignonette, almonds, and other articles, about the period when the fermentation ceases—a process imitated, in this country, in the manufacture of cowslip and elder-flower wines. Could the flavour of fruits be preserved during the process of vinifaction, our strawberry and raspberry might be expected to produce highly scented wines—a circumstance known to be very uncertain, since the result of perfect fermentation is generally to volatilise or destroy the aromatic matter on which this delicate property depends. It is a subject worthy of attention, however ; and the general rules which must guide us in the attempt, are easily deduced from what has been already said."

Having thus glanced at some of the leading points of difference between the wine of the

grape, and other particulars relating to that, and wines produced from our fruits, it only remains to make some general remarks on the manufacture of the latter; for to give recipes for home-made wines would compel us to, in part, convert the work into a "Domestic Cookery" manual. The details and quantities involved in British wine-making for home use, are always given in such a book as that just named; and their number is legion.

A convenient method, on the large scale, of making all such wines, cider, perry, &c., is to use a press, such as is represented in the following cut. The fruit of any kind is placed in a

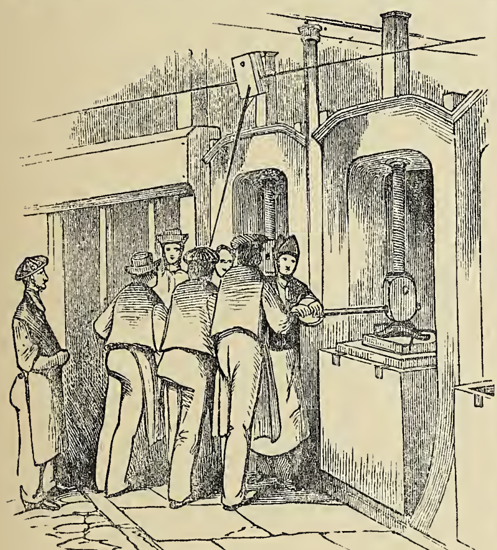


Fig. 368.—Fruit-press.

large trough, in which is a board that covers the fruit, and nearly extends the whole internal and horizontal area of the trough. By means of a hand-screw, this board, or cover, is forced down with great pressure; and, consequently, all the juice of the fruit is pressed out. A still more eligible arrangement is that of the hydraulic press, now employed at large wholesale works for this purpose.

Raisins, the dried fruit of the grape, afford the nearest approximation to a real wine of any of British manufacture, because they contain much grape sugar, that may be spontaneously fermented, just as is done in ordinary wine-making abroad. Being dry, as imported into this country, they are first steeped in water, to extract all soluble matter; and the skins are then put into such a press as we have just described, to force out any remaining liquor. The subsequent processes, after fermentation, are those of racking, fining, sweetening, and bottling.

As regards English fruits, fermentation is not usually carried on with their juice, which, after extraction, is boiled, sweetened, brandied, &c. The manufacture of cider and perry strongly resembles that of the foreign wines, already described in detail; and the result is the production of those well-known sweet-acid liquors, that contain but a small amount of absolute alcohol; have, nevertheless, intoxicating effects; but are not characterised by the stupefying or narcotic properties of malt liquor.

In the west of England, where apples are grown in immense quantities, cider is a favourite beverage, and largely replaces the use of ale. At harvest-time, the cider-cask is a common accompaniment in the field. Placed under a shady tree, to keep the liquor cool, it affords a favourite and refreshing drink for the reaper, and is had frequent recourse to. Indeed, in some of our western counties of England, cider is as much a characteristic beverage as London porter is in the metropolis.

The manufacture of *liqueurs* and perfumes, is, in part, connected with our subjects. Both productions result, more or less, in the solution of flavour, or essential oil, in strong spirit; and the delicacies thus prepared for the organs of taste and smell are often of the most *recherchè* kind. But for reasons already mentioned in respect to giving recipes for making British or home-made wines, we are compelled to omit any details of their manufacture, especially as no scientific interest is in the least involved in the matter.

VINEGAR-MAKING.

The art of vinegar-making fitly terminates, in its description, the various subjects previously dealt with; for it is a final process, either of brewing beer or making wine; and is frequently a result equally feared both by the brewer and wine-maker.

The acid that should properly give the acid taste to vinegar is the *acetic;* and this is familiarly known as the basis of aromatic vinegar, which is the ordinary commercial acetic acid, perfumed with camphor, and various essential oils. Acetic acid, and, consequently, vinegar, results from the oxidation of alcohol, as may be easily proved by putting some strong spirits of wine into a watch-glass, with a little spongy platina, the latter having, at the same time, access to the atmosphere. Owing to the power which the platina has of condensing oxygen and other gases in its pores and surfaces, it brings the oxygen in intimate contact with the carbon and hydrogen of the alcohol. The result is, that the alcohol becomes oxidised; and the changes represented below occur.

Alcohol $= C_4 H_5 O + HO$, becomes converted into

Acetic acid $= C_4 H_3 O_3 + HO$.

In other words, alcohol containing four equivalents of carbon (C), five of hydrogen (H), and one of oxygen, with an equivalent of combined water (HO), becomes changed into acetic acid, composed of four equivalents of carbon, three each of hydrogen and oxygen, and one of water. In these *formulæ*, we have considered both the alcohol and acid in a combined state with water,

or what is called, in chemical science, the hydrated condition. In carrying out the preceding interesting experiment, the watch-glass, holding the spirit and spongy platina, should be covered by a vessel closed at one end. A tumbler inverted over them will answer every purpose.

This method of making vinegar would, of course, be far too expensive in this country, because of the heavy duty on spirits of all kinds; although, in the absence of the excise duty, the method would be both cheap and effective. For commercial purposes, however, either wine or beer is universally employed as sources of vinegar. On the continent, where grapes are abundant, wine is exclusively used; hence the name, *vine*-gar. But in our islands, ale or some old beer, or a wort expressly brewed from malt for vinegar-making, are only employed; hence a name of vinegar, still retained in some parts of the country—*ale*-gar.

The philosophy and practice of vinegar-making are alike simple. Oxidation of alcohol is the result; and this is generally carried out by exposure of the liquor, whether from the grape or malt, at a comparatively elevated temperature, to the action of the air, as by the stove method; to the action of the atmosphere, at temperatures equal to about the average summer-heat, in the open fields—a method called fielding; and, lastly, by a most ingenious plan (adopted, we believe, first in America), by which, dashing the liquor through the air in the form of spray, over birch and other twigs, its oxidation is most rapidly effected. Besides these methods of converting sugar, wine, or malt liquor into vinegar, is that of the vinegar plant, to which more detailed attention will be directed hereafter.

The method of producing vinegar from wine, as practised abroad, is both easy and simple. Wine lees are added to wine; and thus a new fermentation is generated, converting the alcohol, and any other remaining grape sugar, into acetic acid; the new fermentation being kept up until all the wine is converted into vinegar. Fining is then proceeded with, and the liquor becomes fit for use. Continental vinegars, but especially the French, are often flavoured by aromatic plants; as, for example, Tarragon, &c., &c.

Vinegar made in this country is always produced from malted corn, or, occasionally, the stock of the brewer's ale that has gone hard is purchased, which, chemically, however, amounts to the same thing. When made direct from corn, the processes of mashing and the production of wort, are precisely similar in detail to those already entered into fully, in connection with brewing for beer, at *ante*, p. 484, *et seq.*

Fermentation of the wort follows; the boiling with hops, as adopted with beer, being, of course, omitted. The liquor produced by fermentation is, technically, termed *gyle*—a term already used in connection with the fermentation of wort for beer, effected in the gyle-tun (see *ante*, p. 486). At this point, the gyle is equivalent to the wort of the distiller; that is, it contains alcohol, the oxidation of which, as already spoken of above, is the object of the vinegar-maker.

The gyle is converted into vinegar by different methods that we have previously glanced at, and which must now be considered in detail.

By one method, "the liquor"—a strong ale without hops—is distributed into small barrels, set close together in a stoved chamber; and a moderate heat is kept up for six weeks, during which the fermentation goes on equally and uniformly till the whole is soured. This liquor is emptied into barrels after the whole of the alcohol has been converted into vinegar by the action of heat, and the oxidation effected by the atmosphere.

Another method, and that most common in our islands, is that called fielding; and the process may be seen in constant operation, especially in the neighbourhood of the metropolis. An immense assemblage of casks is made in the open air; these being supported on stands. The gyle is run into them as represented in the following cut, by the bung-hole of the casks;

Fig. 369.—Filling the Casks.

and this being simply covered with a tile, partly closing the bung-hole, but allowing of the access of air, the gyle is left exposed to the oxidating influence of the air for a long time, depending on the atmospheric temperature. Gradually the alcohol of the gyle becomes oxidated, and acetic acid is produced, of course simultaneously affording vinegar.

The liquor is then drawn off, and transferred to large vessels, and an important operation has to be performed on it. By long experience it is found that ale vinegar is greatly improved by being passed over, or rather through, a bed of the stalks and skins of raisins, technically called *rape*. There is little doubt that the grape sugar in the raisins has the effect of perfecting the fermentation, besides improving the flavour of the vinegar; although we have succeeded in making, for private use, a vinegar barely inferior to the best English or foreign, by means of the vinegar plant, presently to be described. The rape is placed in double-bottomed vessels, somewhat resembling the mash-tun, described at p. 484, *ante*; and, after passing through the

rape, the liquor is drawn off, and pumped up, so as again to pass through the rape, and so gain the full benefit of flavour, &c., which that material is capable of affording. Ultimately it becomes fit for sale in casks or bottles; but, like ales, porter, and stout, vinegar differs greatly in it flavour, according as it is produced by different makers.

The other method to which we referred, is not only ingenious, but, at the same time, in accordance with strict scientific principles. Instead of the gyle being left to gradual and, necessarily, slow oxidation, it is dashed over twigs, loosely packed in high casks or cylinders, being repeatedly pumped up to undergo the same process until acetification is completed. Of course, in so highly a divided condition as in the form of spray, exposure to the acidifying or oxidating influence of the atmosphere is most rapidly carried on. We have not heard of any vinegar-maker's establishment in our islands adopting the process; but in the United States of North America there are firms that follow this plan, and even grow their own grapes, intended solely for the manufacture of vinegar, using the juice of that fruit in place of the malt liquor universally employed in our islands.

The following remarks, for which we are indebted to the late Mr. Barlow, deserve notice, as suggesting an easy method of making vinegar, on the small scale, for domestic use.

"Vinegar, as well as fruit wines, is often made in small quantities for domestic uses; and the process is by no means difficult. The materials may be either brown sugar and water alone, or sugar with raisins, currants, and especially ripe gooseberries. These should be mixed in the proportions which would give a strong wine; put into a small barrel filled to about three-fourths of its capacity, with the bung-hole very loosely stopped. Some yeast, or, what is better, a toast sopped in yeast, should be put in, and the barrel set in the sun in summer, or a little way from the fire in winter; and fermentation will soon begin. This should be kept up constant, but moderate, till the taste and smell indicate that the vinegar is complete. It should then be poured off clear, and bottled carefully. It will keep much better if it be boiled for a minute, cooled, and strained before bottling."

Lastly, we may notice the vinegar plant, which is a kind of fungus, the spawn of which forms a tough web. Acting on a solution of sugar and treacle, or of coarse sugar containing treacle, it induces a fermentation that eventually converts the sweet liquid into vinegar. By care, in respect to temperature, keeping away dust and dirt, and other such precautions, excellent vinegar may be made by the vinegar plant; and as it rapidly reproduces itself, a whole neighbourhood may be supplied with the means of most cheaply producing vinegar. Occasionally, and as already noticed, an article so produced has a flavour quite equalling the best white wine vinegar. We never tried the experiment, but venture to suggest the use of a few raisins with the sugar, &c.; or the filtration of the vinegar produced from the plant through raisin-stalks and skins, in the manner already stated to be common in the brightening and clarifying of vinegar, as usually pursued, on the large scale, by regular makers of the article in this country.

In making vinegar and pickles, all contact with the ordinary metals, such as lead, copper, iron, &c., should be avoided; for all these are soluble in the acetic acid of the vinegar, and are liable to form deadly poisonous salts. At one time it was a regular practice to boil pickling vinegar in copper vessels tinned over; but as it is impossible to secure at all times the complete tinning of a copper vessel, the practice is of the most dangerous character. Even a silver vessel is as dangerous; for that metal is soluble in hot acetic acid. One of the most eminent pickle-making firms of the metropolis employs a platinum pipe, through which high-pressure steam is passed to heat the vinegar required for their pickle manufacture, which is held in a wooden vat. The acetic acid of the vinegar has no action whatever on platina, and, therefore, no possible source of danger can exist in following out such a method; and, consequently, the plan has every qualification that can recommend it for universal adoption in the trade. The adulterations to which vinegar and pickles are most subject, are the presence of copper (either accidentally or intentionally added), and sulphuric acid, the latter being frequently present in considerable quantities; for, being intensely acid, it affords a cheap means of increasing the profit of the maker by its fraudulent addition. Copper is sure to be present if pickles be boiled in a copper or brass vessel; and its intentional addition is effected for the purpose of giving all, but especially old pickles, a bright-green colour.

Even the naked eye of a practised person may detect the presence of copper in pickles; for with it they assume a bright grass-green colour; whilst pickles that have no copper in them have a dull olive tinge. By putting a clean and well-polished knife into a little pickle suspected of containing copper, this metal will be detected by being precipitated on the surface of the knife in its metallic form; so that it is at once distinguished by the most unpractised person. Another plan is to add as much liquid ammonia to the pickle liquor as will entirely neutralise all the acetic acid it may contain, and leave a strong smell of ammonia. If copper be present, a deep blue colour will be produced, which is an evident and unmistakable sign of the metal.

Sulphuric acid is readily detected by adding a solution, either of the nitrate of baryta, or of the chloride of barium, to a little of the vinegar or pickle liquor diluted with water. If that acid is contained in either, an abundant white precipitate of sulphate of baryta will be afforded; and the test is exceedingly delicate. We may here add, that a small proportion of sulphuric acid is legalised in its presence in vinegar. Physiologically, no harm can arise from that presence; still, an excess is neither more nor less than a fraud on the consumer; and, if used for pickling, it softens and injures the usual articles employed in pickle-making.

In England, the brown kind of malt vinegar

is almost exclusively used as a table condiment; although, for pickling purposes, the distilled or white vinegar is commonly employed. It is much stronger than the brown vinegar, and, consequently, injurious to pickles, softening them. Its action on human teeth is great; and, besides, it is entirely destitute of that fine flavour that brown vinegar usually possesses. In Scotland, during a residence of several years, we never saw a drop of brown vinegar once brought to table, either in private houses or at hotels; the white or distilled vinegar being in constant and common use. The reason of this opposition of custom is difficult to account for; but it is as marked as any other habit distinguishing the natives of England and Scotland. On either side, it may, however, be properly observed, *De gustibus*, &c., &c.

We shall conclude this account of the manufacture of vinegar by quoting some remarks by Dr. Moleschott, in reference to its dietetic and general qualities.

"That which renders vinegar so favourite an addition to food is a peculiar acid. * * * * From *acetum* (the Latin name of vinegar), this acid is called the acetic; and it is to be obtained from all spirituous beverages. But as alcohol yields, in addition to the acetic acid, a quantity of water [see *ante*, p. 507], both malt and wine vinegar contain, in proportion to the acetic acid, more water than is to be found in either beer or wine, in proportion to the quantity of alcohol. Of wine, or French vinegar, about one-twentieth, in weight [or 5 per cent.], consists of pure acetic acid. In an inferior vinegar, this acid does not even amount to more than one-fiftieth to one five-and-twentieth part in weight.

"Vinegar, therefore, is always a considerably diluted solution of acetic acid, containing, in addition, a small proportion of albumen and sugar, gum, and of several organic substances, especially of some colouring matters, which differ according to the liquor from which the vinegar is prepared. [This, of course, refers only to brown vinegar.] Thus, in wine vinegar there is some acid tartrate and sulphate of potash to be found; and in wine and fruit vinegars, a proportion of tannic acid, to be attributed to the husks and skins of the fruit. Acetic ether, as passing over into wine vinegar from some kinds of wine [see *ante*, p. 501, in respect to the *bouquet* of some wines], communicates a fine agreeable fragrance to the vinegar. If the acetous fermentation has not entirely ceased, the vinegar will still contain a small proportion of alcohol, which, by a further accession of oxygen, becomes decomposed into water and acetic acid.

"Vinegar assists digestion. With the exception of legumin [the albuminous principle of peas, beans, &c.], it dissolves the albuminous substances, transforming, in a short time, even the gluten and fibrine into a gelatinous mass; hence vinegar and butter are useful concomitants of fish; and vinegar promotes the digestion of meat.

"As acids are capable of transforming cellulose [woody matter] and starch into sugar, the vinegar added to salad is likewise to be regarded as a mixture promoting digestion. Thus, in the majority of cases, the use of vinegar is a custom founded on good reasons. Only in soups of peas, beans, and lentils, vinegar is to be rejected; as by it, even if added in excess, the legumin is brought into an insoluble state.

"The dissolving action of vinegar upon other albuminous substances goes even as far as to the blood. Beverages containing vinegar have a dissolving effect on blood, and are cooling; and in milk, the proportion of caseine [that is, cheese] cells, containing the butter, decreases if the mother take much vinegar.

"And because of this solution of the most important constituents of the blood, manifesting itself by a greater liquefaction, it would appear an unpardonable frivolity, or a lamentable ignorance in young girls, to endeavour, from vanity, to produce, by means of vinegar, artificial thinness: only too often, in attaining their aim, they incur dangerous and deeply-rooting diseases, which deprive them of their more beautiful maiden bloom."

On account of pickles being made with vinegar, the remarks just quoted equally apply to their use; but with this qualification, that the solid matter they contain, whether cucumbers, onions, beans, cauliflower, or other material, may become a disturbing element to delicate digestive organs. As a rule, however, their use, within due moderation, is not only harmless, but beneficial; for they exercise a wholesome stimulating influence on the digestive action of the stomach, and especially tend to prevent biliary disturbances when fat meat is too freely partaken of.

BREAD, AND BREAD-MAKING.

At the commencement of this chapter, it was remarked, that the association of sugar, malting, brewing, &c., with the manufacture of bread, would seem exceedingly incongruous to a person unacquainted with chemical science; but the perusal of the preceding pages, and of the facts, &c., that have now to be brought before the reader's notice, will evidence that such an arrangement is not only consistent with our present scientific knowledge, but necessarily arises from a study of its laws.

Bread, in some form or other, has ever been a mainstay of life in most nations. From the earliest history of man, as given in the sacred writings, mention is made of "cakes." From the persistent manner with which eastern nations maintained for ages traditional customs, we may suppose that their modern mode of making cakes little differs from that followed in the time of Abraham. Flour, ground in a rude mill, worked by hand, is fashioned, by water, into round or oval cakes. "A fire is kindled upon the ground, and when the earth is sufficiently heated, the fire is removed; the dough is next placed on the heated spot, covered with hot ashes and embers, and speedily baked. Another method resembles this, excepting that, instead

of the bare ground or hearth, a circle of small stones is arranged, and these being heated, the paste is spread over them, and then overlaid with hot cinders; the cakes thus baked are thinner than the former, and are used by the Arabs for their morning meal. A third method is rather curious: there is a circular pit dug in the earthen floor, about three feet in diameter by four or five deep; hot embers are placed on the bottom of this pit, and the dough, brought to the form of large round or oval cakes, is dexterously thrown against the sides of the pit, which are smooth and clean, and are heated by the embers; here the cakes become soon baked through, and are removed just before they have a tendency to fall into the fire. Another method consists in the use of a circular earthenware pan or vessel, for containing the fuel, the cake-dough being stuck against either the exterior or interior of the sides of the vessel till baked. Sometimes cakes are made as thin as a wafer, by applying a soft paste to the heated surface of the pan, where it is baked almost instantly, and removed as a thin scale or film. Occasionally, also, an iron plate is laid over the open mouth of the vessel, and the bread is baked on that. Some of the wandering tribes make use of a slightly convex sheet of iron or copper, supported about nine inches from the ground, on a few stones, and heated by a slow fire beneath; the cake-dough is laid on the plate, and quickly baked." In some parts of the East, where the population is settled in villages or towns, the baker "has his shop in the market-place, where he exposes his baked bread and cakes for sale; and behind him is the oven where the baking is carried on, formed by a kind of recess in the wall, one-half of which is occupied by the fuel, and the other half by the cakes, which are baked in five minutes."

Primitive as some of these methods may appear, they are used, in a modified style, in many parts of Europe; as, for example, Italy, some places in France, and other southern countries. Amongst many of the interesting discoveries that have been made by the opening out of the buried Pompeii, that of a baker's shop, in full operation at the moment of the destruction of

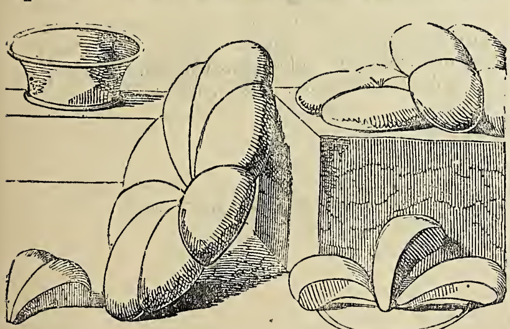


Fig. 370.—Bread from Pompeii.

the city, is by no means the least interesting. The loaves represented in the preceding cut, had retained their shape as when first baked, although, of course, they had become as hard as a board.

The methods of grinding corn, as described in Holy Writ, are still in use in Egypt, and other eastern countries—being a hand-mill, as represented in the following cut. The entire mill

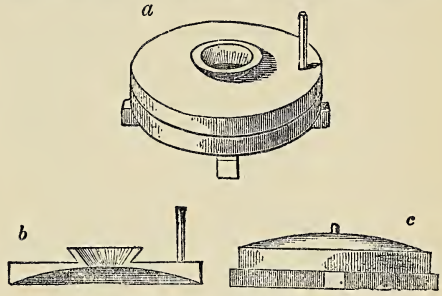


Fig. 371.—The Hand-mill.

is shown at *a*. It consists of an upper stone, *b*, into which an under stone, *c*, fits, the convexity of the one suiting the concavity of the other. The corn to be ground is introduced into the central opening of *b*; and the mill is worked by the handle shown in *a*. Just the same method is still adopted, at the present day, as was 2,000 years ago. Two women seat themselves on the ground, opposite to each other, holding between them two round flat stones; in the middle of the upper one is the cavity for pouring in the corn; and this stone has the handle, as just explained. One woman pushes it by the right hand to the other, who drives it round again to her companion. The left hands of each are used to supply corn to the mill as it becomes ground into meal.*

The Arab corn-mill, represented in the following cut, is of such simple construction as to

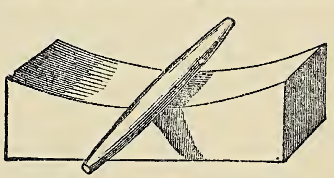


Fig. 372.—The Arabian Mill.

scarcely require description. It consists of a hollow stone and roller, which reduces the grains of corn to a coarse powder by rolling them.

A very ancient method of corn-grinding was that which resembles the use of the modern pestle and mortar. In China this plan is still adopted to bruise or grind rice; and such a mill, worked by the foot, is represented in the following cut.

Such are a few of many interesting facts of the history of bread in countries the most civilised of the ancients. In the later days of the Roman empire, the art of bread-making seems to have acquired great perfection; and the cut (Fig. 373), illustrating what we should take to be the pantry of a respectable house at

* See Matthew, chap. xxiv., v. 41.—"Two women shall be grinding at the mill," &c., &c.

Pompeii, reminds us of an almost similar arrangement, in domestic affairs generally, as is now adopted in our own houses. In the centre

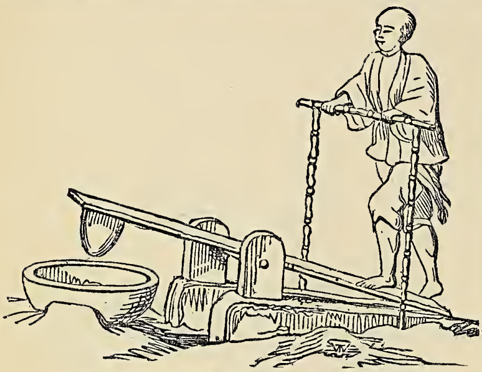


Fig. 373.—The Chinese Mill.

will be noticed a dish full of small cakes ready for table. The other accompaniments also suggest a love of good cheer.

The use of wheat and corn seeds generally, seems to date from the earliest history of man in countries where such crops can be advantageously grown; whilst millet and rice have been largely employed in other countries, the heat of which is too great to permit of the growth of wheat, &c.

In America, again, Indian corn, or maize, began to be known by us, as food, shortly after that continent was discovered by Europeans, who thus found a new source of bread, long before employed by the natives of America,

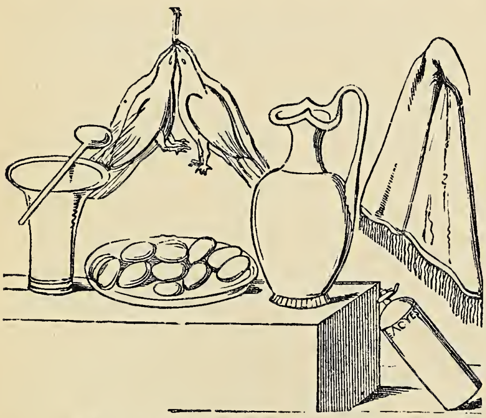


Fig. 374.—Bread from Pompeii.

and, at the present time, rapidly spreading, in growth and consumption, in most parts of the world where the climate is favourable.

Modern corn crops are almost entirely confined to wheat, in all temperate countries, for bread-making; although rye, barley, and oats have all been used for the same purpose. But for the possession of all the best qualities as a bread-stuff, wheat exceeds any other cereal. It is a remarkable fact, that all the sources of bread-stuff at the present day, in civilised and semi-civilised countries, are derived from the Grass order, or *Gramineæ;* as, for example, wheat, rye, barley, Indian corn or maize, millet, rice, the sugar-cane, &c.

Our readers are all too familiar with wheat

Fig. 375.—Ear and Plant of Rice

and other corn crops, to require description of any of them. The three following, however, being never seen grown naturally in temperate climates, claim a few words of notice.

Rice, the *Oryza sativa*, is an article of food for scores of millions in Asia, America, and Africa,

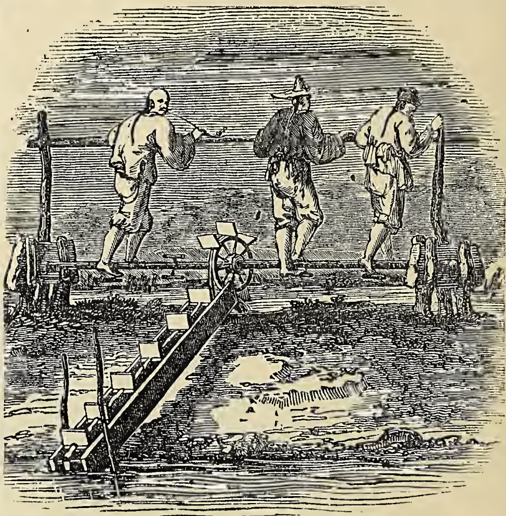


Fig. 376.—Chinese Irrigation.

in all of which it is cultivated to an enormous extent. It is also grown in some parts of Italy, and Southern Europe generally, only, however, to a small extent, compared to what is produced in India, China, and the Southern States of North America. It grows wild in India; and

it was most probably introduced thence into China, where its use can be traced for at least 5,000 years back. The finest quality of rice is that produced in the states of Carolina, in North America. The cut (Fig. 375) illustrates the appearance of an ear of rice, and the plant itself. It is a crop that requires an abundant supply of water. The Chinese grow their rice in soil about six inches deep, resting on clay, which tends to keep the water on the ground. The soil is covered with water to the depth of about three inches; and the plants, first sown in beds, are then transplanted to fields just described. By irrigation (a method of which is illustrated in Fig. 376), the fields are kept flooded until the rice is ripe, when it is reaped and stacked till required for threshing, in a manner very similar to that we adopt for wheat, &c.

Millet, *Panicum miliaceum* and *italicum*, has long been used as a bread-stuff in India and China. An ear of Italian millet is represented in the annexed cut. It is grown in a similar manner to rice. In Egypt millet is also largely grown. A kind called Guinea-corn, the *Holcus vulgare*, forms a most important article of bread-diet, amongst the lower classes in Egypt, at the present day. Species of millet are also obtained from wild grasses of the genus *Sorghum*, which exist native in some parts of South Europe, North Africa, &c. An Indian species belongs to the genus *Setaria*.


Fig. 377.—Millet.

Buck-wheat is a source of bread utterly unknown to us in these islands, but much used on the continent. It has no right to the term "wheat;" for it neither belongs to the corn species nor the grass order. In this country, the order to which it belongs—the *Polygonaceæ*—is represented in the Dock, a familiar field-weed in most parts of our islands; the garden rhubarb; and, in Asia, by the species of rhubarb from which the well-known purgative root is derived. In this country, buck-wheat, however, grows, and is commonly known by the name of *Brank*. It bears heads of white flowers, tinted with pink at the edges of the petals, and grows rapidly. It is especially suitable for poor sandy soils. In Germany, it is as important an article of food as the potato is in Ireland, amongst the lower classes; and it is also esteemed amongst the better class of society there. As a daily food, it is made into a kind of porridge, resembling that made from oatmeal in our northern counties, and in Scotland. The grains are also converted into a form resembling our pearl barley; and they are much used by distillers to produce the spirituous liquor called *Goldenwasser*.

The preceding are the chief of corn plants, with the addition of buck-wheat, that are used for making every kind of bread or cakes. They are all characterised by containing three essential constituents for the maintenance of animal life, whether of man or the domestic animals. These constituents are, respectively—*saline matter*, such as phosphate of lime, which, with the carbonate of that earth, is necessary to form bone, and the skeleton structure generally; *nitrogenous matter*, on the presence of which, in bread, depends its power of forming flesh, and that is found in wheat in a condition called *gluten*, because of its glutinous quality when moistened with water; and, lastly, *starch*, or heat-giving matter, which, entering into the circulating system, at last becomes completely decomposed, and, by the combustion of its carbon on the lungs, and, to a lesser degree, in other parts of the body, affords and sustains animal heat. Of these, wheat contains 60 per cent. of starch, and 13 of nitrogenous or flesh-forming matter: Indian corn has very nearly the same constitution as wheat; buck-wheat has 50 per cent. of starch, and $8\frac{1}{2}$ of nitrogenous matter; rice, 74 of starch, and $6\frac{1}{2}$ of nitrogenous matter; Indian millet, 70 of starch, and $8\frac{1}{2}$ of nitrogenous matter.

It will be thus seen that there is no part of the habitable globe where any extent of population exists—that is, from 50° to 60° north and south of the equator—that does not possess some kind of grasses, the seeds of which may be converted into bread; and that, further, the chemical constitution of all such seeds is, in every way, such as to afford all necessary nutriment for the sustenance of animal life in health and bodily strength.

Omitting such starch products as arrowroot, sago, tapioca, &c., that are not made into bread, although used for similar purposes as articles of food, we may briefly notice some substitutes for corn-bread that are used chiefly in hot climates, and where the plants producing them are usually indigenous.

Quinoa, the farinaceous seeds of the *Chenopodium quinoa*, belonging to the Goose-foot order, or *Chenopodiaceæ*, becomes a chief article of food on the slopes of the Andes, of Chili, Peru, and Central America. *Gero*, belonging to the grasses, the *Penicillaria spicata*, affords, by the seeds of the plant, a bread-food of large use in the neighbourhood of the Niger, the Gambia, and the western shores generally of Africa. *Guarana bread* is similarly used in Brazil; it is procured from the seeds of the *Paullinia sorbilis*. The flour of the seeds is made into rolls, which are made into a paste with water by grating them with the tongue of a fish; and the paste, or porridge, is sweetened before use. *Macaroni* and *Vermicelli*, of such enormous use in some parts of Italy, are produced from a hard-grained kind of wheat, called *Grano duro*. After the seeds are powdered, the meal is made into a kind of paste, that is forced through tubes having a wire core; hence the peculiarly worm or tube-like form of those articles.

In many hot climates, the *Banana* and *Plantain* afford, by their fruit, an article that is

made into a kind of bread; the pulp of the plantain being made into loaves for that purpose. The *Bread-fruit, Artocarpus incisa*, a native of the South Seas, but now grown generally in hot climates, is also much used as a bread substitute. The fruit represented in the following cut has a very singular appearance,

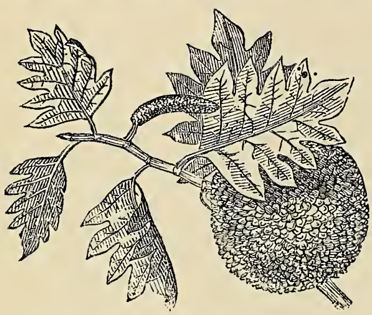


Fig. 378.—The Bread-fruit

somewhat resembling a pine-apple exteriorly, being covered with excrescences like that fruit, but rounder in shape. When used to afford a substitute for bread, the fruit is plucked before it is ripe, cut into slices, and baked. It then much resembles bread made from wheat; but has a far finer texture. It is largely used as a bread-food in the islands of the Pacific Ocean; and both its appearance and taste, which is sweetish, recommend it generally to the palate. The *Jack-fruit*, or *Tchacka*, is similarly used. Its fruit resembles the bread-fruit, but is very much larger. The bread-nut, the fruit of the *Brosimum alicastrum*, belonging, like the two preceding, to the order *Artocarpeæ*, is used in place of bread in some parts of the West Indies and the north of South America.

In the collection of Economic Botany, at Kew, a singular kind of bread may be seen. It is produced from the bark of a species of fir in Finland; and when the powder is baked, it presents the appearance of a brown-coloured cake, interspersed with white-coloured grains. It has been used chiefly, in times of scarcity, in the inhospitable climate of Finland. It will be in the memory, however, of many of our readers, that some years ago, when the price of wheaten bread rose so high in this country, successful attempts were made to convert various kinds of woods into a bread material. Only absolute necessity, however, would induce the use of such a product by us; and that extreme cause is never likely to arise in our islands.

The yam may be last named as a bread substitute; and its source is from below ground, being a tuber of various species of plants of the genus *Dioscorea*, twining shrubs of tropical climates, generally resembling the potato, but of closer texture, and larger size; some of them, in fact, reaching in weight, each of from thirty to forty pounds. It may be cut into slices, and baked into biscuits. If ground, it produces a flour, or meal, that may be made into bread, or used like wheat flour for a great variety of domestic purposes. The tuber of the *Jatropha manihot*, by pounding and washing, affords a meal which, when baked, produces what is called *cassava* bread. We have thus described, perhaps, every source of savage and civilised life, of bread or bread-substitutes; the latter, however, before use, being made to resemble wheaten or other corn-bread as much as possible in form, taste, and other qualities. Of course all notice has been omitted of such vegetable products as the potato, "vegetables," and other sources of food not capable of assuming the bread form; as such, with the exception of the potato, which is often mixed with wheaten flour, have no relation to the subject before us. The perusal of the list that has been sketched out, proves, in a remarkable manner, how universal is the taste amongst mankind for bread; and, as we first showed, that taste is as ancient as it is universal.

Our attention must next be directed to the best means that can be adopted to render the material for bread suitable for its purposes; and, for the sake of simplicity, our remarks will be exclusively devoted to wheaten bread, it being the type of all others, and the most nourishing.

We have already noticed, that the chemical constitution of wheat-flour is just that which answers every purpose of nutriment to man, and equally so to the lower animals; but in respect to these, its high price forbids its use as an article of food. The 60 per cent. of starch that wheat flour contains, is an invaluable source of heat to the animal. Arriving in the stomach, it becomes, with the other food partaken of, converted into chyle, and, as already mentioned, finds its way, in an altered state, to the lungs; where, exposed to the action of atmospheric oxygen, it undergoes a slow combustion, precisely in the same manner, although less in degree, as do the coals of our domestic fire-place, or steam-boiler furnace. The other constituent of wheat flour (that is, the 13 per cent. of nitrogenous matter, chiefly in the form of gluten), supplies that which tends to form the albumen, caseine, and fibrine of the animal system—substances all containing nitrogen, and forming the fleshy part of the system. The saline ingredients have also been noticed, and we need not here further refer to them.

If some wheaten flour be put into a muslin bag, and exposed to the action of running water, the starch will pass off, and may be collected in any vessel beneath, as a white powder insoluble in cold, but readily altered and dissolved in hot, water. This constitutes the heat-giving portion of wheaten flour and bread.

On examining the inside of the bag, it will be found that a sticky or adhesive substance has been left by the starch. This is equally insoluble in cold water, although it is made adhesive by the action of the liquid. This gluten, as already explained, is the flesh-producing portion of bread.

Lastly, if a few grains of wheat, or wheaten flour, be burnt at a red heat in a crucible, or on a spoon of platina, or its foil, a white matter is afforded, which is the saline ash that

the wheat contains, and which goes to supply the salts of the body. The chemical analysis of this ash requires much care and experience ; and we shall therefore leave it by simply repeating that it contains the major portion of the saline matter, soluble and insoluble, that the body of man and the domestic animals require.

In reference to the general composition of the *ceralia*, or corn-producing plants, we shall quote, with modifications, the following remarks of an eminent physiologist, who has devoted a life-long attention to dietetics :—

"The difference in composition which exists amongst the seeds of the ceralia, is much greater than one would expect from the natural affinity of their parent plants.

"Gluten and starch are the constituents of grain, in the proportion of which the greatest differences are found, the quantity of one generally varying inversely as that of the other [see *ante*, p. 514].

"Potash considerably predominates over soda in the seeds of the ceralia. * * * Maize, or Indian corn, is remarkable for its considerable proportion of fattening matter [containing, as it does, a large amount of oil, once extracted for burning and other purposes]. In the external covering of all kinds of grain, there are contained much more gluten and fat than in the interior. Peeled rice and pearled barley have therefore lost a great deal of their nutritiveness; and bread containing bran is much more nourishing than that prepared from sifted flour ; but, unfortunately, the former is rendered, by the hard cellular tissue which it contains, much more difficult of digestion than the latter, and excites an injurious irritation, causing diarrhœa in weak digestive organs. Sifted flour is therefore, for general use, preferable to the unsifted."

* * * * *

"*Constituents of Bread.*—Although bread is made of different cereals in different countries, * * * * wheat and rye furnish the flour chiefly used in the preparation of bread in Europe [see *ante*, p. 512, *et seq.*, for account of the usual sources of bread].

"Ordinary bread, prepared with leaven or yeast, is therefore called leavened or fermented bread. Leaven is nothing else than a part of the common dough preserved until the next baking, during which it has become sour. By the process of fermentation in this preserved dough, lactic and acetic acids are produced. Yeast is substituted for leaven with precisely the same effect. In both, a nitrogenous compound is the occasion of the sugar formed in the dough turning into a vinous fermentation. By this process the sugar is decomposed into alcohol [see *ante*, p. 470], which evaporates, and carbonic acid gas, which, enclosed by the dough-gluten, is retained, temporarily, in the bread.

"Now, the ferment, water, and salt form the dough. In this a part of the starch has been already transformed into sugar ; and, by the action of leaven or yeast, this sugar is transmuted into alcohol and carbonic acid [see article *Brewing*, under the head of fermentation, at p. 486, *ante*]. The carbonic acid, which is prevented from escaping by the tenacity of the gluten, produces vesicles, or cells, which give to the bread its ordinary lightness. By the process of baking, a portion of the starch in the external layer of the bread is transformed into gum and sugar. The soluble albumen coagulates in the process, and the alcohol evaporates.

"By exposure to heat, the crust becomes brown ; a compound of an agreeable bitter taste is thus formed, similar to that produced by roasting different other organic compounds. The peculiar bitter principle thus formed has been called *roast-bitter*, or *assamar*. Bread is so easily soluble in water that it is liquefied even by the humidity of the air.

"Good wheaten bread is of a white colour ; but real brown bread—as, for example, the well-known Westphalian rye bread, called Pumpernickel—is made from rye. As wheaten flour contains more gluten than rye flour, the same proportion of gluten is not found in white and brown bread; and as it is the gluten which causes the sugar to undergo fermentation, and retain the carbonic acid in the cells it thus forms, the reason is apparent why rye bread, which contains a smaller proportion of gluten, is less spongy than wheaten bread.

"Stale bread is scarcely drier than fresh. In five days, fresh bread loses one-hundredth part only of its amount of water ; and it will become stale even if it has been cooled in an atmosphere saturated with moisture. But stale bread may be re-transformed into fresh if put again into the oven, whereby a considerable amount of water is necessarily lost. Both high and low temperatures cause a change in the smallest particles, which fact has yet to be more closely investigated by science. It is, however, a fact, that stale bread is hard and firm, but not dry.

"*Nutritive Qualities of Bread.*—Bread is not, on the whole, so nutritious as meat, so far as the albuminous substances are concerned ; for even the richest bread contains only two-thirds of the quantity of albuminous matters, as compared with beef.

"The digestibility, moreover, of bread and flesh is not to be considered equal ; for gluten is more difficult of solution by our digestive juices than the fibres of the muscles, and corresponds less intimately with the albuminous substances of the blood ; therefore it is more slowly transformed into the constituents of the latter.

"The starch so abundant in bread has to be transformed into fat. The inferior solubility peculiar to the ready-formed fat of the flesh is thus compensated.

"Of the fat that the excretions subtract from the blood, bread is a much more productive source than meat ; for about two-thirds of wheaten bread consist of starch ; while only a small proportion, in weight, of gum and sugar is contained in it. The predominance of the constituents of fat, explains why bread contains more of solid substance than does flesh. In bread the proportion of water scarcely amounts to one-third of the whole.

"This abundance of the constituents of fat does not at all correspond in proportion to the small quantity of fat to be found in the blood; and in comparing the nutritiveness of flesh with that of bread, we must therefore decide in favour of the former.

"The nutritiveness of the different kinds of grain is dependent upon the comparative proportion of gluten; for, in all of them, the constituents of fat are present in abundance. * * * * Chemical knowledge justifies the old usage, which prefers wheat and rye bread to all other kinds of bread."

The preceding remarks show clearly the chief points of nutritive value that the cereals generally possess in the form of bread. It must be remembered that, in old and emphatic words, man doth not live by bread alone. On the contrary, as a rule, bread is more of an adjunct, at least in our islands, generally, than a sole sourse of sustenance or food. The morning meal of tea, coffee, or cocoa, accompanied with butter-milk, bacon, and sugar, includes, in all these items, precisely the same elements that are contained in bread, but in very different proportions. All, however, contain, at the same time, most of the essentials for heat-giving, flesh-forming, and bone-building; hence bread can only be considered as part, but by no means the essential, of such a meal. Equally the same remarks apply to the meal "tea." In respect to dinner and supper, amongst the middle and lower classes, the essential value of bread is greatly diminished; for, by an almost invariable rule, meat, potatoes, fat, beer, cheese, and vegetables, form the constituents of dinner at least, and some of them of supper. We therefore are compelled, referring to the custom of our islands at least, to limit the value of bread as a source of nutriment.

But further, bread, as a rule, is rarely eaten alone in this country. Even amongst the poorest of our agricultural labourers, an abundance of milk may at all times be obtained at a nominal price, as the skimmed milk of the dairy; and in this condition, although diminished in nutritive value, still it contains caseine, albumen, and saline matter, all of which add to the nutritive character of the meal, conjoined with the use of bread. The old-fashioned meal of the labourer generally, in the absence of meat, is "bread and cheese," moistened by either ale or cider, and, none the less harmlessly, by cold water. So that, taking the physiological aspect of bread, on the whole, its assumed general importance as an article of daily nutriment, although really high, is usually too highly estimated. For our own part, half a pound of bread daily has been the highest average for the last twenty-five years; and, from observation and extended inquiry, we have no reason to be considered in an abnormal condition of bread consumption.

So far for the constitution and nutritive qualities of wheaten bread. Its manufacture, according to different systems, must next engage attention.

Wheaten flour, and the grains of wheat, taken in the stomach in an undivided state, are generally highly indigestible to most constitutions, because the gluten is so tenacious in its character as to be all but indivisible in that organ. Indeed, if taken in that undivided state, it forms an adhesive coat to the walls of the stomach, that is scarcely less injurious than an inside lining of gutta-percha, india-rubber, or marine glue. On three different occasions we have witnessed a narrow escape from death, owing to obstructions thus caused. In one of these a young lady had been out with a pic-nic party to the corn-fields at harvest time, for the purpose of gleaning. On her return home, the gleaned ears of wheat were picked out, bruised, and made into a kind of paste with new milk. An abundant meal of this caused an obstruction in the bowels, that nearly proved fatal, within twelve hours of the meal having been partaken of. Hence the necessity of opening out cells in the gluten, by which its mass is so divided, that it may become readily soluble in the stomach, and so afford its nutritive powers in place of becoming positively harmful, if not dangerous. It is the absence of this division of the gluten in pastry, that causes in it, and all unleavened bread, their indigestibility. But of this we shall speak more fully hereafter.

As already pointed out, two methods to produce fermentation, and the consequent division of the gluten—by leaven and yeast—exist. Leaven is simply a portion of dough; that is, flour and water made into a paste, which has been allowed to undergo partial fermentation, and has hence attained the power of propagating that fermentation in fresh dough. Consequently, a small portion of such fermented dough, or leaven, if added to fresh dough in a large mass, causes fermentation to proceed through the whole, just as we have already pointed out at p. 483, *ante*, that almost any form of fungus will produce fermentation in vegetable solution to an almost unlimited extent. Truly, it may be said, "a little leaven leaveneth the whole," so great is this property of catalytic action (see *ante*, p. 486) on vegetable and, indeed, animal matter.

But the use of leaven is attended with injurious consequences to the flavour of the bread; hence brewer's yeast is now almost invariably substituted for "leaven." The leaven of previously made dough communicates frequently a sour flavour to the bread, which yeast does not. Brewer's yeast can generally be obtained in any of our large towns, to almost any extent. But, independent of this, are various mixtures, as German yeast, &c., that may be employed by the baker, and so save him a considerable amount of time and pecuniary loss, that would occur in an uncertain supply of yeast for his wants.

Making dough is one of the first operations of the baker. At times he mixes various proportions of boiled potatoes, which generally compensate for the loss that the wheaten flour undergoes during its fermentation; for, as already pointed out, a portion of it is converted into alcohol and carbonic acid. Proportions of the potatoes, flour, water, ordinary or patent yeast,

with salt, are well stirred together, and left in a mixed condition for some hours, dependent on the temperature; and thus a mixture is procured by which fermentation may be engendered. This liquid generally is strained before adding to the bulk of the flour to form the dough. On being worked up with a due proportion of flour, the mass so produced is left to stand from four to six hours. Owing to the action of the yeast, the mass swells, greatly increasing in all directions, owing to the disengagement of carbonic acid gas, which, as already explained, distends the gluten to form cells, on the presence of which the lightness of the bread afterwards made from this dough will depend. At this portion of the operation, owing to the formation of such cells, the dough is called "sponge;" and, technically, again the act of leaving it to gain that condition is similarly named. After a time, water with salt is worked up into the sponge, and the mass is increased by about three times the amount of flour already used, the whole being vigorously worked up together, so as to make an even or homogeneous mass. This is then left for an hour or two, to prove, and being cut up into proper sizes in respect to the weight of the intended loaf, is ready for the oven.

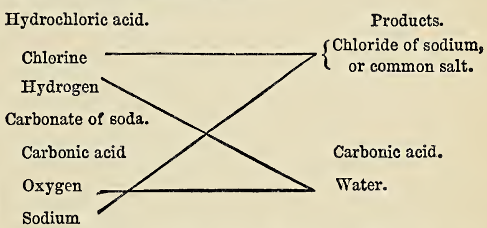
Meanwhile, the oven, which consists of a dome-like cell, has been under process of heating—not by a furnace at the top, sides, or bottom, as is common in the ordinary kitchen range, but by placing a fire within it. When the oven is thus sufficiently heated, it is cleaned or swabbed out, either by wet rags tied to a stick, or by a wet mop, so as to remove all soot or other cause of dirt. The loaves are then placed in side by side, by means of a kind of long wooden spade, and there left until the baking is completed. The oven is then "drawn" —that is, the loaves are removed—and a little scraping or grating of the crust prepares them for the customer.

The chemical and physical effects of baking are those of hardening the gluten cells, and portions of the starch, converting the external coating of the crust into a kind of gum, producing the bitter substance already named at p. 515, *ante;* and driving off the alcohol, a large portion of water, and any other volatile substance; as, for example, acetic acid, when unsound flour is used—a circumstance of no uncommon occurrence in the cutting trade, as we shall hereafter notice. Externally, a portion of the carbon of the flour is set free, that causes the black appearance of the burnt crust.

It is evident, from the preceding general outline of the process of making bread, that the success of the operation will depend on the quality of the flour employed, and the complete working or fermentation caused by the action of the yeast. And further, that by the latter a portion of the flour must be lost by its conversion into alcohol and carbonic acid. Several other objections occur to this method; for if the yeast be not good, the flavour of the bread is materially injured; or fermentation may proceed too far, acetic acid be produced, from the same causes as we explained in connection with the manufacture of vinegar, at p. 507, *ante*, and the "batch," or baking, materially injured, or made unsaleable.

To obviate all these objections, and also to replace the rather dirty operation of kneading by the hands (possibly by the feet), chemical and mechanical means have been proposed by various inventors, who have received a varying, but by no means an adequate, degree of success or reward.

One of the first proposed methods was that by which, in place of using yeast, and effecting fermentation of a portion of the flour, the carbonic acid was produced, and the salt requisite for the bread at the same time, by taking hydrochloric acid and carbonate of soda, in just such proportions as that they should neutralise each other. Now, common salt, that is always added to dough in the manufacture of bread, is composed of chlorine and the metal sodium. In hydrochloric or muriatic acid, chlorine is an essential constituent; whilst the carbonate and bicarbonate of soda contain the metal sodium and carbonic acid gas. Consequently, when hydrochloric acid, and a solution of carbonate of soda in water, are added together, common salt and carbonic acid are produced, as illustrated by the following *formula*:—



Hence the water and salt enter into the constitution of the bread, if such a mixture as above described be added to flour during kneading; whilst, at the same time, the gas evolved during the combination of the acid with the soda salt enters into the gluten, and expands it into cells, in precisely the same way that the same gas does when produced by the fermentation of flour by yeast.

The least that could be said of this plan is, that it was very philosophical, and fully accordant with the requirements of physiology, and a clever adaptation of chemical and physical laws. Its great recommendation was, that it entirely would do away with the use of yeast; lessen the risk of the loss that bad or putrid yeast often occasions; and, at the same time, it introduces nothing whatever that could cause the least injury to the health of the consumer. On the contrary, it added salt, which, as we have stated, is requisite.

From various causes, however, this method ended in total failure. In fact, the bread was far too good for the public to appreciate. Not being bleached by means to which we shall presently more fully allude, it did not attract the eye. The cell-pores, again, were rather smaller than those produced in the ordinary

operation of the baker, who uses yeast, and, consequently, the quartern or half-quartern loaf looked smaller than that supplied by the ordinary baker. From this and other causes, that need not be entered into, the plan, and the company that was formed to carry it out, simultaneously came to grief.

To obviate the objection of using the hands or feet in kneading the dough, an inventor patented a plan by which the kneading was effected by means of curved knives, working in a trough containing the dough. This plan was unobjectionable, and entirely did away with the necessity of hand-work. And here, saving the delicacy or taste of our readers, we are compelled to state, that after a journeyman baker has been for some time engaged in the operation of kneading dough, his arms are affected by a peculiar disease, attended with the growth of parasitic animals. We enter no further into details, leaving the imagination of those who peruse our pages to fill up any void of description that we shall not attempt to give. But, independent of such an unpleasant consideration, it must be added, that the life of a working baker is, perhaps, the most arduous of any industrial occupation that man follows. In our opinion, it is infinitely worse than coal-mining, and more permanently injurious to health. The report of a government commission, appointed some years ago to investigate the subject, disclosed a far more hideous state of things than had ever been previously discovered in reference to factory operatives. Out most of the morning, delivering bread to the customers; preparing the sponge for the night's baking; attending to this for a large portion of the night, with, consequently, little or no rest night or day, a baker must either have the inducement of large profits, or the blessing of patience, creditable to any one to carry on a business requiring such constant and fatiguing attention.

An ingenious machine has been invented by Mr. Paul Pfleiderer, of London and Stuttgart, by which the operation of kneading and mixing dough or other materials is effected by steam or other power. The inventor states that it is the best machine yet produced for kneading and mixing materials for bread, biscuits, macaroni, vermicelli, lozenge, and other manufactures, as well as for wholesale confectioners, large cooks and pie-makers. The machine is represented in Figs. 380 and 381. Fig. 380, giving a general external view, is suitable to work $1\frac{1}{2}$ cwts. of dough at a time, or to turn, say one-third sack of flour into biscuit dough. Fig. 381, which shows the machine open, is suitable to work about 5 cwt. of dough at a time or, say, to turn one sack of flour into dough.

The company to which we last alluded, although at first successful, eventually was completely ruined by an act of carelessness in the use of bad yeast—a fact that leaked out in a trial between one of the workmen and the firm, and thus was added another to the list of failures in attempting to improve the art of bread-making. One of the latest improvements was that effected by the invention of Dr. Dauglish, about the year 1859—'60. It has the recommendation of doing away *entirely*, from the pouring of the flour out of the sack to the delivery of the baked loaf to the baker for his customer, of any hand-work whatever. In fact, the operative baker has scarcely anything more to do than to look at the process, keep the materials supplied, and to attend to other minor details.

Instead of producing the carbonic acid gas, that is to swell the gluten into cells, by either fermentation or the addition of hydrochloric acid and carbonate of soda (two separate methods already fully explained), the expansion of those cells is effected by mechanical means. Our readers are all familiar with the fact, that so soon as a bottle of soda-water is drawn, the water and gas run out simultaneously with great force. The essential part of Dr. Dauglish's process, so far as the cell-expansion is concerned, is dependent on an adaptation of that fact on the large scale.

He first prepares the water to be used in making the dough, by placing it in a strong vessel, similar in principle to that used in making soda-water. Carbonic acid gas, produced by the action of sulphuric acid on chalk, is forced into the water at a pressure of one hundred pounds to the square inch, by which the water is caused to retain many times its bulk of the gas so long as the pressure is maintained. The gas is carefully washed, in order that no impurity whatever may pass over with it into the water to be used in making the dough. The flour and salt, in due proportions (the latter being dissolved in water or brine), are conveyed, by a shoot and tube, into a large vessel, which is then closed air-tight. The water containing the compressed carbonic acid gas, in solution, is then admitted to the flour, and the whole is kneaded together for some time, by means of a rotating cylinder of knives, until a complete mixture of the aërated water, the flour, and the salt is effected.

Of course the gas in the water still exercises its pressure in the vessel containing the dough, diminished by entering into a larger vessel than it previously occupied; but still the pressure is very great. When the kneading has been fully effected, an attendant opens the lower part of the vessel containing the dough; and this being full of condensed carbonic acid gas, enormously expands as it escapes, being, in appearance, like thick froth. This is cut off by the attendant with a knife, transferred to a tin at once, and weighed.

By means of a kind of shoot, or inclined trough, the tins are then conveyed to the mouth of the oven, and are placed in this in the usual manner, and left till properly baked.

It will thus be perceived, that during the whole of the process the hands of man never come into contact with the bread, the whole operation being conducted by machinery. Again, all necessity or use of fermentation is avoided, because of the complete mechanical expansion which the carbonic acid gas effects on the dough as the latter issues, at great pressure, from the

kneading vessel. All danger of dust and dirt, insects, &c., &c., is done away with, because all the vessels are air-tight; and hence, a cockroach, or a piece of tobacco (by no means uncommon discoveries in an ordinary loaf), are rendered impossible to be found. The bread, too, when baked, is remarkably light, of even texture, and excellent taste; and, altogether, the process reflects the highest credit on the ingenious inventor. We regret that its success has not been equivalent to its merits.

The engraving (page 522) illustrates the entire process. The flour is passed by the shoot, H, into a spherical vessel, F, in which knives rotate, moved by the cog-wheels, G, and which supersede manual labour in the process of kneading. The carbonic acid gas is produced in the vessel B, which contains chalk; this being decomposed by the gradual addition of a dilute acid, supplied by the Archimedean screw, C. The gas, after being carefully washed with water, is forced into the receivers, E, which are filled with pure water; the latter rapidly absorbs the gas, in a manner similar to that adopted in making soda-water. The aërated water is passed, under great pressure, into the vessel F, in which the flour is undergoing the process of kneading. After a time the dough is allowed to escape from this kneading-vessel, at L, and, on coming out of this opening, it rapidly expands, owing to the action of the gas in its pores. Thus the minute cells are produced without the employment of yeast, which, from being sour or putrid, often materially injures the bread, and renders it unwholesome. The dough is received into tins, and conveyed by a railway to the oven, N; and is, therefore, *never touched by the hands of the baker* during any part of the process. The remaining letters indicate various portions of the motive power of the machinery, and the steam-boiler.

A stupid prejudice was created by interested persons against this process. A statement was published, to the effect that oil of vitriol and chalk were used to make the bread. This is perfectly true in the right sense; but utterly false in that sense in which it was intended to be understood. The chalk and sulphuric acid are used in precisely the same manner as they are in making soda-water and lemonade; but they have no more to do with these beverages than with Dr. Dauglish's aërated bread, except so far as they furnish pure carbonic acid gas for both purposes. Indeed, the vessel containing them might be placed miles away from the soda-water maker, or one of Dr. Dauglish's bake-houses, provided a pipe extended from them to convey the gas into the water in either case. The maliciousness of such a coloured statement only was equalled by the gross perversion of fact that it was founded on. But, as is always the case wherever vested interests are at stake, conscience has her mouth closed, and falsehood is made a cloak for malice.

It will be unnecessary for us to enter into any description of the various articles of fancy, in bread and pastry, that are made from flour. In respect to artificial flavours, now so largely used, we have already given extended details, in connection with the art of distilling at page 493, *ante;* and refer our readers, therefore, to that part of the work for details of one of the most interesting discoveries in chemical science that have been made during the present century.

The manufacture of biscuits by machinery has now become one of great magnitude and importance, whether for ship use, or for ordinary sale in the shops. The first attempt was made at Gosport, in 1831, where Messrs. Rennie, the celebrated engineers, erected machinery for the Government, to supply the navy with sea-biscuits. The principle of the construction of all such machines is—The dough is mixed by knives, or blades, in a trough, until all the ingredients are perfectly incorporated. The mass is then conveyed to the breaking-down rollers, which travel backwards and forwards on an iron table, on which the mixed dough is placed. Here it is spread out so as to destroy all lumps, and the dough soon becomes completely kneaded. By means of a stamping press, the biscuits are formed out of the flat mass thus produced, and are then conveyed to an oven to bake. By this method, a number of biscuits, limited only by the number of machines, may be produced with surprising rapidity.

Adulteration of Flour and Bread.—In connection with each subject that has been treated on, we have thought it right to touch on the question of adulteration, to which the various articles of food or drink that we have described are accidentally or fraudulently subject; and in none do we find a question of greater importance and extent than in bread and flour.

Several years ago, a commission was appointed to investigate the subject of adulteration generally; and a difficulty occurred as to what meaning should be attached to the term. For example, reducing the strength of spirit by adding water might strictly be considered an adulteration; but for reasons already assigned, in respect to the adulteration of porter, at p. 488, *ante,* we incline to the opinion that such a course, as simply lowering the strength of a liquid by an addition perfectly harmless, should not be considered an adulteration. On the other hand, if *cocculus indicus,* and other such poisonous matters, be added, no two opinions could be held on the point, whether a gross, fraudulent adulteration had been committed by an offender.

We have already pointed out, at p. 489, *ante,* that the Act there alluded to, its provisions and penalties, and subsequent amendments, have resulted little in preventing the continuance of wholesale adulteration of almost every article of food and drink. And here we take the liberty of repeating a suggestion we made to a Member of Parliament, who interested himself much in the question whilst the first Act was before the House of Commons. It was to the effect, that every person found wilfully adulterating, or selling, with knowledge of the fact, an adulterated article, should, on second conviction, be compelled to exhibit in his window a bill stating the fact, and the circumstances of his conviction. This would be a moral way of nailing his ear to

his own door-post, as it is said the Chinese do, physically, in such cases.

Articles of the largest sale are those generally chosen for subjects of adulteration. Hence wine, beer, spirits, tea, coffee, and bread undergo this operation to a wholesale extent. We have analysed samples of these in most of the large towns in England and Scotland, and do not hesitate to say that, in every one, adulteration of the articles just named is carried on to a shameful, or, perhaps, shameless degree.

Flour and bread are, to a certain extent, fermentation, owing to the production of acetic acid; the vinous fermentation producing alcohol, as already explained, in using good flour, proceeding another step to acetous fermentation. Now, the addition of carbonate of ammonia neutralises the acid, forming the acetate of ammonia; and so the sourness of the bread is cured.

Often, on visiting a chemist's shop at hours when regular customers may not be expected, a man, in the garb of a baker's assistant, may be seen there, or leaving with a heavy parcel under

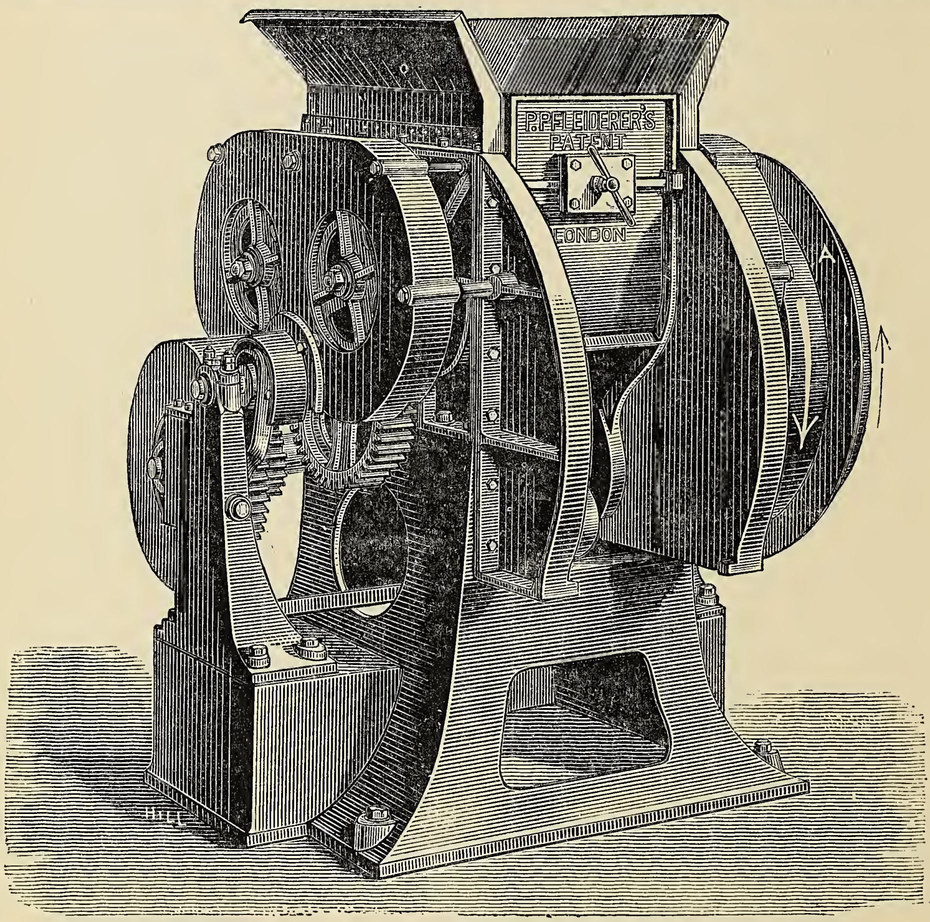


Fig. 380.—The Universal Kneading and Mixing Machine, for Bread, Biscuit, and Confectionery Making.

similarly adulterated; plaster of Paris being chosen for the former, to make up weight; besides pea, potato, and other starch flours that are also added, as cheaper than wheat flour. Ground bones have also been discovered as similarly employed.

Low-class flours are brought up to the mark of colour by means of alum, sulphate of copper, and carbonate of ammonia, mixed with the dough in making bread. If a flour has gone sour from damp or other cause, it is highly probable that it will become more so after

his arm. It certainly cannot contain common salt; for the baker can buy that commodity as cheap as the chemist. If by accident the parcel were to fall on the pavement, and the paper broke, the secret, and its object—*alum*—would be both let out of the bag at once. The alum is used to whiten bread made of inferior flour; and to so great an extent is it used, that crystals of it may be picked out of some bad bread. Not long ago we found two in a small loaf; and our esteemed friend, the late Dr. Normandy, whom we have previously mentioned, and who

took so active a part in these questions, stated that he frequently met with such cases. Once we saw a bundle of crystals of washing soda in a loaf, that had been used for purposes just named, for cheapness' sake, in place of carbonate of ammonia.

Pipe-clay, magnesia, and many other substances besides plaster of Paris, are added to flour, on making bread, to increase weight, or remove actual or probable acidity.

On one occasion we were requested to give an opinion as to the reason of illness of a whole family, seven in number, that was evidently caused, not by any sudden attack, or accidental poisoning, but by the cumulative results of some substance constantly taken into the system. The house-drains were suggested as the cause; but these proved blameless. We analysed the water supply for lead, but none was found; and great care was taken at all times to keep the water wholesome. Accidentally partaking with them of a meal, the secret was at once discovered. The baker was supplying the family with bread that was literally dosed with alum. On analysis, we discovered several grains in one loaf; and having given a written report on the matter, this was shown to the baker, who indignantly denied the fact at first, but who, on being threatened with legal proceedings, was glad to put himself on a more modest scale of pretension, and at last to admit his guilt.

A simple way of discovering alum is as follows:—Take the soft of the suspected bread; cut it up into small pieces, and soak it for four or five hours in a basin of water kept hot in an oven, taking care not to let the water evaporate all away. Remove the basin, and pour its contents into a piece of muslin, so as to retain all the solid part, but to let the liquid run through into another vessel. Place the latter, holding the liquid, in an oven, and evaporate until all the water, with the exception of a teaspoonful or two, has passed off, and put this to cool. When cold, any alum present will be seen in the form of

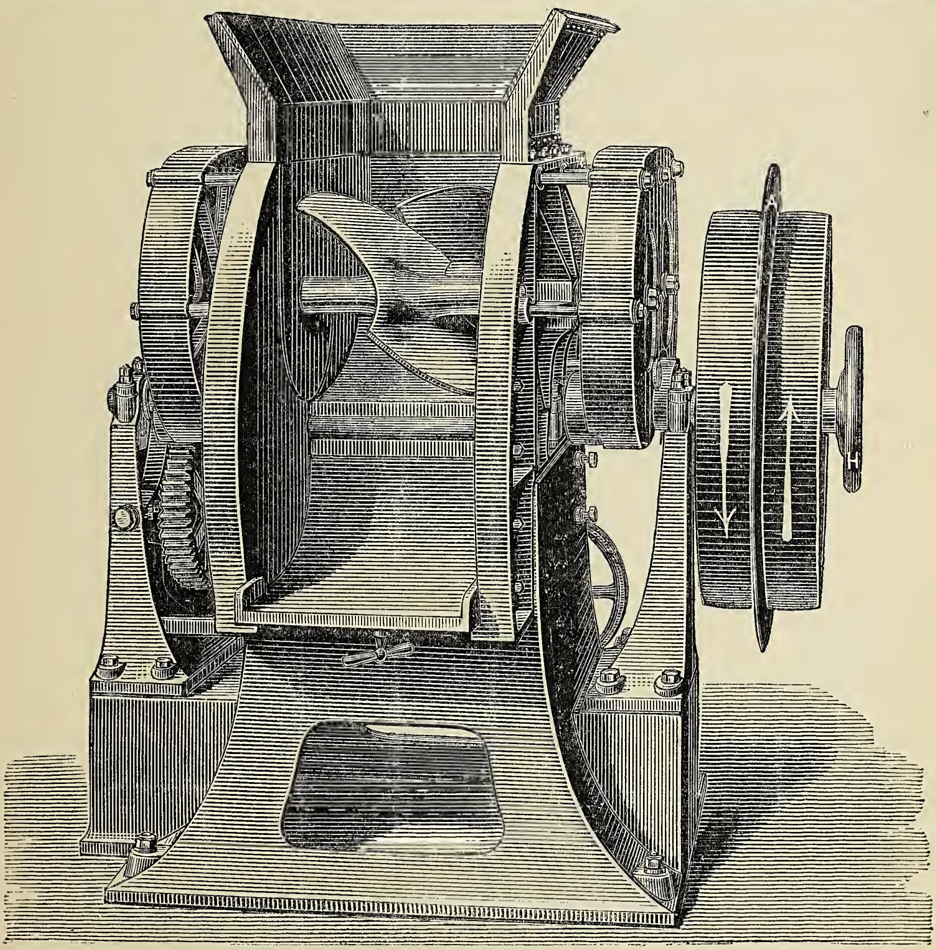


Fig. 38[illegible].—The Universal Kneading and Mixing Machine, shown open for the discharge of finished goods or cleaning.

crystals, and may at once be recognised by the taste. If any white powder be discovered, it may be either plaster of Paris, burnt bones, or any other of the mineral substances already named, that are insoluble in water.

By putting some of the bread into warm water, and adding a few drops of yellow prussiate of potass in solution, a copper or mahogany colour will be produced if sulphate of copper be present.

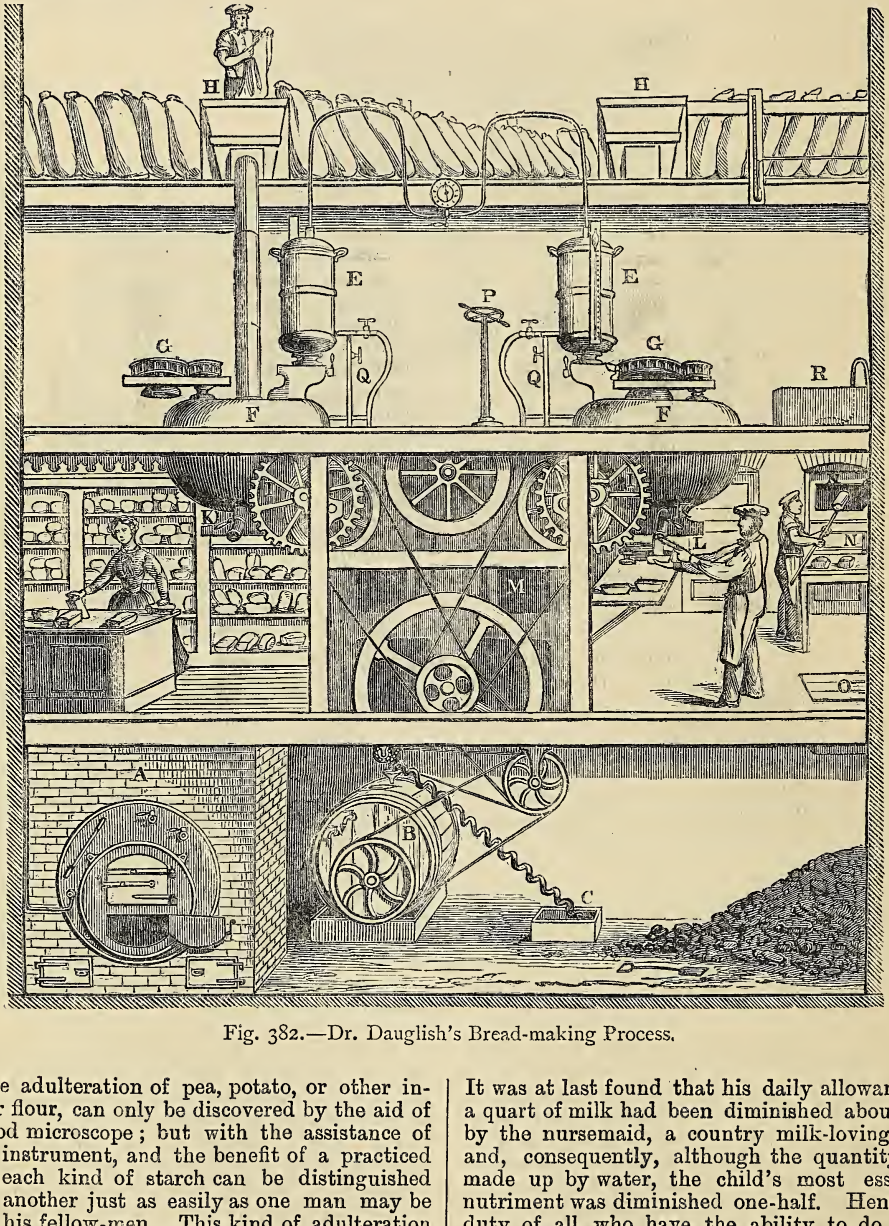


Fig. 382.—Dr. Dauglish's Bread-making Process.

The adulteration of pea, potato, or other inferior flour, can only be discovered by the aid of a good microscope; but with the assistance of that instrument, and the benefit of a practiced eye, each kind of starch can be distinguished from another just as easily as one man may be from his fellow-men. This kind of adulteration is exceedingly common, but harmless; at the same time it is an injustice, and, as such, the practice ought to be checked. In some families, especially amongst the labouring classes, bread is the staple food of children; and anything that diminishes the amount of nutriment that they should partake of, may produce serious consequences, not only in their infancy, but also in after-life. But a short time ago, the writer discovered that his son looked constantly pale, and more sickly than usual. The child had a liberal allowance that affection, custom, and science could suggest as fit and nourishing. It was at last found that his daily allowance of a quart of milk had been diminished about half by the nursemaid, a country milk-loving girl; and, consequently, although the quantity was made up by water, the child's most essential nutriment was diminished one-half. Hence the duty of all, who have the ability to do it, to check, as far as they can, a system of fraud, that affects not only the pocket of the ignorant and poor man, but also his own family's health.

CHAPTER XIV.

BRICK; POTTERY GENERALLY; CERAMIC WARE; GLASS, ETC., ETC.

IN the Introduction to this work, pp. lv. to lxv., the early history of brick, pottery, glass, &c., has already been briefly traced. It will be seen that much difficulty exists in ascertaining the exact details of the subject, as in most cases our information is made up of imperfect remarks from ancient and profane historians. The remains of early brick and pottery are generally found hap-hazard, and therefore, except in comparatively recent times, no date can be assigned to their manufacture either individually or as typical of the time of their production.

Many of the vases, bottles, and pans of ordinary quality were very similar to those made in Egypt at the present day; and they seem to have had a great variety of Coptic names applied to them. "Coptos and its vicinity," says this writer, "were always noted for this manufacture; the clays found there were peculiarly suited for porous vases to cool water; and their qualities are fully manifested at the present day in the *goolleh* or *bardak* bottles of Queneh. That the forms of the modern *goollehs* are borrowed from those of an ancient time is evident, from the fragments found amidst the mounds which mark the site of ancient towns and villages, as well as from the many preserved entire; and a local tradition affirms, that the modern manufacture is borrowed from, and has succeeded without interruption to, that of former days. . . . The Egyptians displayed much taste in their gold, silver, porcelain, and glass vases; but when made of earthenware, for ordinary purposes, they were sometimes devoid of elegance, and scarcely superior to those of England before the classic taste of Wedgwood substituted the graceful forms of Greek models for the unseemly productions of our old potteries. Though the clay of Upper Egypt was particularly suited to porous bottles, it could not be obtained in a sufficiently pure quality for the manufacture of vases like those of Greece and Italy; in Egypt, too, good taste did not extend to all classes, as in Greece; and vases used for fetching water from a well, or from the mill, were frequently of a very ordinary kind, far inferior to those carried by the Athenian women to the fountain of Callirhoë."

The same authority informs us, that when the Egyptians gave an entertainment, one of the most usual preparations consisted in decking the apartments with vases. The wealthy had vases of hard stone, alabaster, glass, ivory, bone, porcelain, bronze, silver or gold; while those of more humble means were obliged to content themselves with vases made of glazed pottery or of common earthenware. Many of these ornamental vases were very graceful in form. Some of the most elegant specimens which have been found at Thebes are supposed to have been wrought so far back as fifteen hundred years before the Christian era, at a time when almost every other country was (so far as is now known) in a state but little removed from barbarism.

Much distinction must be held between two classes of ware of the oldest date. The greater portion was of the unpolished sort; and many of such kinds were used as cooling vessels, by the use of which wine and any other beverage might be reduced in temperature. The Egyptians, Romans, and other nations, availed themselves of porous vessels for such purposes, just as we may do at the present day; and it is far more than probable that, although abundant specimens of polished or a kind of glazed ware have been preferred, yet, as almost all the early specimens of pottery have been obtained from nations anciently dwelling in hot climates, this valuable property of cooling by porous pottery largely extended, and gave special value to the art in former times.

It may also be noticed, that all the early specimens of pottery, whether lamps, vases, urns, or other objects, are made of coloured and opaque clay, generally free from all signs of vitrification. Many of the Greek and Etruscan specimens are highly ornamented externally. Black on a red ground is exceedingly common; but numerous instances occur in which more than one colour was laid on, apparently in much the same style as that we now adopt—viz., by transferrence from a material on which the pattern is drawn to the object to be ornamented; a method that will be more particularly described hereafter. The black pattern on many of the ancient vases is, doubtless, the result of the application of charcoal, which, so far as we know, apart from heat, is altogether indestructible; hence the perfection with which the specimens in our museum are characterised, after the lapse of at least 2,000 years.

The design, again, is generally in accordance with highly cultivated taste. There is none of the villanous "willow" and "rose pattern" of our day. Generally the designs of the best class of ware were of an historical character; and the execution of that, the drapery of figures, and,

generally, the *tout ensemble*, vies with, and frequently exceeds, the best efforts of modern times, especially if we take into consideration the fact, that the material of the early potter was, so far as Greece and Italy were concerned, infinitely inferior to that of which we avail ourselves in modern times. Of course, in these remarks we entirely except the productions of the Chinese, to which we shall presently fully allude.

Some of the designs of Greece and Italy handed down to us are, if we may say so, domestically historical; that is, they afford us an insight into the habits of the household of those days. Just as, in our time, we make presents to our children of pots painted to represent some place, or a nursery scene, or, indeed, any other familiar object of daily life, so some specimens of ancient pottery represent games, the occupation of the toilet, bath, &c., &c. Humanity, apart from the conventionalities of life, is the same in all ages, from the time when Joseph said, "Put my cup, the silver cup, in the sack's mouth of the youngest,"* unto the present day; and it is this unity of *now* with what *was* ages ago, that lends a leading charm to the pursuit of every branch of study and research that the intelligence of man can engage in.

"With regard to the admixture of colours" on early varieties of pottery, "it is thought that the first specimens were simply outline delineations, no fresh tint being added to the colour of the clay; and that black was afterwards used to represent shadow. Some of the early writers speak of the red colour being produced by cinnabar or vermilion, and that a cheaper red was formed of minium, or red lead. Sometimes the figures were black, and the nerves picked out with white for effect; at others the figures are of two colours, black and dark red, the muscles of the body and the plaits of the vest being represented by scratches only; while other specimens have red figures upon a black ground, the effect being heightened, in the earlier period of the art, by a rudely-scratched outline; but, at a later time, by a more careful delineation, often tinted with other colours. According to the number of colours on the Greek and other specimens, the terms 'monochrome,' or single-coloured, and 'polychrome,' or many-coloured, have been employed designatively."

We must now turn to a higher class of pottery ware, as first involved in the productions of that ingenious people, the Chinese.

It will be unnecessary to state that the term "China" has long been applied to the higher classes of pottery ware, from the fact that it first became known in Europe through the Portuguese having brought early specimens of that ware from China, in some of their enterprising commercial voyages. It has been stated that the Romans were acquainted with the porcelain manufacture of China; but we fail to find any sound basis for such an opinion. We must either give credit to an amount of "overland" transit, as existing between China, India, Egypt, and Italy, in former days that is impossible in our own, or admit that the Romans were better navigators than ourselves, to lend the slightest credence to such a statement. Much fabulous matter has been introduced into an account of the early methods of the Chinese in respect to the manufacture of porcelain. We quote the following as a matter for interesting perusal by our readers, without in any way endorsing its correctness. Mr. Davis is the authority here quoted, although he also relies on the account of D'Entrecolles, an enterprising Jesuit of the seventeenth century, for some time resident in China :—

"The government of China, for more than a thousand years past, has paid much attention to the manufacture of porcelain, and especially to that at King-te-chin, which pertains to the chief city Jaou-chow-foo. The emperor, Kieng-loon, sent a person from Pekin, to make drawings of the whole process in detail. In a voluminous Chinese work, the subjects of these drawings, which were twenty in number, are described at length. They commence with the process of procuring the materials—*kaolin* and *pe-tun-tse*—and making the paste; then is represented the business of preparing the ashes for glazing, and mixing them with the silica, so as to form a thick liquid. Earthen cases are provided, in which to bake the ware, the round portions of which are turned in a lathe, and the others made in a mould. The subject of another picture is the selection of the blue material, which is supposed to be cobalt. After being turned in a lathe, or formed by a mould, the unturned 'biscuit' is finished by smoothing and paring off all inequalities by the hand; the portions taken off being pounded, and worked to a milky consistence, to be used by the painters. In painting the ware, one set of people designs the outline, and another fills in the colours; and the Chinese say that this division of labour is intended to 'concentrate the workman's hand, and not divide his mind.' It is said that, previous to baking, the same specimen of ware passes through twenty hands; and that, before being sold, it has gone through more than double that number. The pictures proceed to represent the baking of the ware in open and in closed furnaces; and when it is completed, the process of binding it with straw, and packing it in tubs for sale. The whole series of drawings concludes with the ceremony of sacrificing and giving thanks to the god of the furnaces; and this god, according to D'Entrecolles, owed his origin to the difficulties encountered by the workmen in executing some orders from Pekin on account of the emperor. Several models were sent from thence, of a shape and size which defied all the efforts of the people to imitate them; and though representations were made to that effect, these only served to increase his majesty's desire to possess the specimens required. With a view to meet the emperor's inclination, much money and labour were spent, and both rewards and punishments held out to the people employed, but all in vain; when one of the workmen, reduced to despair by the result of his unavailing efforts, threw himself into the red-hot furnace, and was

* Genesis, c. xliv., v. 2.

MOSAIC AND TESSELATED PAVEMENTS.

instantly consumed. The story says, that the specimens then baking came out perfectly fine, and conformable to the model; and from that time hence, the unfortunate victim passed for a divinity, becoming the god of furnaces."

The latter portion of this narrative must, of course, be considered as chiefly fabulous. We have some personal knowledge of the Chinese; and, as an illustration of the vivid power of their imagination, the following anecdote may be interesting to our readers. Having invited three Chinese to dinner, the morning of their visit was chiefly spent in the laboratory, explaining many leading points and experiments of modern science, in relation to heat, light, and electricity. Two matters deeply struck the minds of these individuals, who were of a high order of intelligence, and who had not only received an excellent education in their own country, but had travelled through most parts of Southern Asia, Australia, America, and Europe. To excite their attention, we first ladled out, by the naked hand, several pounds of red-hot lead from a melting-pot—an act that seemed to excite their horror. On bringing, however, the blade of a penknife into contact with the wires of a very powerful voltaic battery, and seeing it instantly converted into flame and sparks, their terror was so excited, that the three instantly rushed from the laboratory. Before parting with them in the evening, we asked the most intelligent to write the names of several common objects, and each of their designations was characterised by idea, rather than expression of fact. Requesting our own name, with which they were perfectly familiar, to be written down, the desire was at once complied with; but, instead of that which our readers may see on the title-page, we were called "the man that laughs at fire, and brings light out of water."

We have thus imperfectly traced some of the most interesting portions of the history of brick and pottery ware, so far as information in any way to be relied on, and evidently in part fabulous, is known. It is impossible to point to any artistic occupation of mankind in which so little change in material, mode of manufacture, design, and general progress has been made in the course of thousands of years. Most articles of domestic use in pottery have either been copied, more or less, from the products of remote ages, or in a great measure resemble them. As already pointed out in regard to design, the modern system of even our best ware only differs in elegance and perfection of execution, but not in absolute character, from that which characterised Egypt, India, China, Greece, and Rome twenty or thirty centuries ago. But, in respect to material, this want of change is at once explained, for none other than the generically termed "potter's clay" could answer the requirements of the art. The character of the product, however, varied with the nature of the material.

Nearly allied to the art of Pottery is Mosaic work, of which, for the present, only a brief notice can be given. It has its analogue at the present day in the ornamental tiles in use for a great variety of purposes.

That variety of pavement or flooring which consists of *mosaic* or *tessellated* work was very extensively employed by the Romans, as is evidenced not only by the pavements of still existing buildings, but in the excavated ruins of Pompeii. The specimens of this art there brought to light are principally composed of black frets, or meandering patterns, on a white ground, or white ones on a black ground. The materials of which they are chiefly composed are small pieces of black and white marble, and red tile, some larger than others, so as to take a deeper hold in the mortar than the rest, and thus form a sort of bonding-course, giving stability to the whole. These pieces are set in a very fine cement, laid upon a deep bed of mortar, which served as a base.

Various very remarkable specimens of mosaic have been from time to time brought to light in different countries. At the end of the last century a mosaic pavement was discovered near Seville, in Spain, at a small depth below the surface of the ground. It was forty feet long by thirty wide, and contained in the centre a representation of the circus-games of the ancients, while on three sides were circular compartments containing figures of the Muses, &c. In the race-course a busy medley of events was depicted, such as a chariot overturned, the charioteer thrown, horses in confusion, and horsemen dismounted; while several spectators are looking on at the sports. In the compartments, besides the representations of the Muses, were centaurs, children in variously coloured tunics, and animals of various kinds. The floor between the different compartments also exhibited various birds, fruits and flowers, and great diversity of colour was exhibited throughout the whole.

Another specimen, dug up near Lyons, was composed of small cubes of marble, interspersed in some places with pastes of different colours.

We now turn briefly to the history of the porcelain manufacture of our own country, which, together with that of France and Dresden, may be considered as the culmination of an art that has been shown, not only to be of the highest antiquity, but of universal pursuit by civilised and savage man.

We have already noticed that the Romans, most probably, introduced the art of pottery into Britain; and that, at the present day, frequent discoveries of mosaic work, vases, &c., &c., indicate that the art was here practised to a high degree of perfection, either by them or by the natives under their direction. Staffordshire, in the district now called the "Potteries," seems to have been, even at that period, a favourite locality for the exercise of the art. And the probability of such being the fact, is heightened from the circumstance that clay, fit for some kind of ware, has always been found in that county.

Dr. Plot's *History of Staffordshire* (*cir.* 1686) states, that, in his time, there were abundant evidences that the art of pottery had been practised for centuries, especially in the neighbourhood of Burslem, still one of the chief places in the "Pot-

teries." One of the chief, if not the leading manufacture of that date, was of "Butter-pots;" and he states, that "the factors buy their butter by the pot, of a long cylindrical form, made at Burslem, of a certain size, so as not to weigh above six pounds at most, and to contain at least fourteen pounds of butter."

As in many other arts, so in pottery, it is related that the discovery of the art of glazing was made accidentally. A servant near Burslem was making a strong brine by boiling in an earthen vessel, when some of the liquid running over to the outside, the external heat of the fire produced a glaze on the surface; and a neighbouring potter, a Mr. Palmer, hearing of this, was not slow in turning it to profitable account. Salt being readily obtainable from beds at hand, facilitated this application of that material for the purposes of pottery-glazing.

The following account is the substance of a tradition, which, according to many authorities, laid the foundation of the pottery district, and its enormous and profitable manufacture. It is quoted, in the main, from a scientific journal of some considerable eminence. About the year 1690, a very remarkable circumstance of the extension of the potteries of Burslem occurred. At that time, the East India Company were in the habit of importing, from the East, unglazed red porcelain vessels, of a beautiful red colour and form, which had never been equalled in England, on account of the want of proper clay. It was discovered, however, that at Bradwell and Brownhills, near Burslem, a fine-grained and beautifully tinted red clay could be procured; and this, together with an abundant supply of coals for the ovens, led to the establishment of a pottery at Bradwell, by the Messrs. Elers, of Nuremberg. Here they made red porcelain unglazed teapots, simply of the fine red clay of the district, as also black or Egyptian porcelain,* by adding manganese to deepen the tint. The brothers Elers seem to have been in advance of their neighbours, and to have taken extraordinary precautions to baffle curiosity. The servants employed were ignorant and stupid, and the thrower's wheel was turned by an idiot. Each person was locked in the place where he was employed; and such were the precautions to preserve the supposed secret, that, previous to the workpeople leaving at night, each was subjected to a rigid examination. However, all these precautions were fruitless; for two persons, named Twyford and Astbury, succeeded in worming out the secret. The former got employment in the works; and by manifesting entire carelessness and indifferenee to the nature of the processes, he masked his real object, which was to find out all that was new in the operations at Elers' works. Of the other man, Astbury, the account handed down is very remarkable. Having assumed the garb and appearance of an idiot, with all proper vacuity of countenance, he obtained employment at the Bradwell manufactory, and received the cuffs, kicks, and jeers of his fellow-workmen in a manner accordant with his assumed character. He was put from one occupation to another; having, apparently, just sense enough to make him worth the pittance which he received. Meanwhile he lost no opportunity of observing the processes and working apparatus; and, on returning home each evening, he formed models of the several kinds of implements, and made memoranda of the processes. He continued this practice for nearly two years, until he ascertained that no further information was likely to be obtained, when he availed himself of a fit of sickness to continue at home; and this was represented as very malignant, as a means to prevent any person visiting him. After his recovery, the Elers seemed to have a suspicion that he was too clever for them, and he was discharged; but they soon found that he had taken their secret from them; and had the mortification to find the Burslem potters avail themselves of methods which they thought rested with themselves.

Staffordshire has by no means lost the credit of producing or containing shrewd men, who, like Twyford and Astbury, could disguise their true condition to obtain their ends. We could point out more than one instance of the same kind in other trades, where an individual has similarly acted. Within our own personal acquaintance, a bleacher, who could not understand how a competitor succeeded in producing far better goods than himself for the Manchester market, pursued a precisely similar course. But although he realised a large fortune, we question whether the price he paid for his conscience was equivalent to what is generally considered as a fair exchange for conscience—morality—even in trade.

The two enterprising individuals to whom we have alluded—Twyford and Astbury—began the pottery business at Shelton, a few miles from Burslem, and carried on both red and white work. It is related, that Astbury, being compelled to seek a cure for partial blindness of his horse during a journey to London, stopped at Dunstable. Here the ostler of the inn at which he stayed attempted to cure the diseased equine eyes by first calcining flint by fire, and then pulverising it, blowing the dust into the horse's eyes. The sharp intelligence of Astbury perceived the fine white powder that the black flint had thus been reduced to; and, on getting home again, he introduced a new era into the art of pottery, by commingling the powder of calcined flints with the clay, previously used alone, by which he obtained several advantages, to which we shall more particularly allude when we arrive at the practical part of our subject.

It must be noticed that, in respect to quality, design, form, &c., the pottery of the time to which we now allude was of an exceedingly crude, rude, and unartistic character; and it was reserved for Wedgwood, to whom we have already alluded at a previous page, to give such an impetus to the trade, as not only suddenly to raise it beyond its then level, but also to place it, in a brief period, subsequently, in a position to compete with some of the best manufactures

* A beautiful specimen of this kind is in our possession as a heir-loom, descended from a relation, who was acquainted with the Elers.

Josiah Wedgwood

that were then carried on in any part of Europe. He laid the foundation, in fact, of our present eminence in the art of pottery, that permits us to even excel the productions of Sèvres, Dresden, and other noted localities.

For a full account of the life and labours of Josiah Wedgwood, we must refer our readers to the biography named at foot ;* but the eminent benefits he conferred on the pottery trade, and the great improvements he effected, demand that we should briefly state some facts in connection with him.

He was born at Burslem, in 1730; and, at the early age of eleven, worked as a "thrower" for his father—thus early commencing his career in the trade. He subsequently entered into the manufacture with a partner, and established two factories at Burslem for making green tiles, imitation tortoiseshell, white stone pottery, &c., and afterwards turned his attention to cream-coloured ware. By selecting the choicest models of Grecian, Roman, and Italian styles, he speedily outstripped all others in the trade in respect to the elegance and excellence of the articles he produced; and, in fact, made his factories at Burslem an attraction for visitors of refined taste. He attempted to purchase the Barberini vase, which has been already referred to in the Introduction. It fell into the hands of the Duke of Portland, who, to persuade Wedgwood to let him have it, promised its loan to the potter as a model. Wedgwood produced fifty copies, which were sold at fifty guineas each. Subsequently Queen Charlotte extended to him her patronage, and he thus became appointed potter to the queen. He had already established a house in London for the sale of his manufactures. With a keen eye to attracting customers to this establishment, he instructed his manager "to do the needful with the ladies in the neatest, genteelest, and best method;" or, in other words, to attract female customers by fascinating their eyes and tastes for elegance in design. To improve in every possible way the style of his goods, he employed leading artists to produce designs: in fine, in the words of his biographer, "pottery, in his hands, became a noble art, worthy of the devotion of princes; and his energy it was, in conjunction with that of the other mighty industrial leaders of his time, which increased the productive powers of the nation to an extent before undreamt of." We may add, that what Watt was to the steam-engine; Arkwright, Crompton, and Peel in the cotton-trade; so Wedgwood may be considered as the founder and father of the refined art of pottery as now followed in this country.

When means of traffic became enlarged by the formation of the Grand Trunk Canal, Wedgwood built a large factory on its banks, and a village for his workmen, which still goes by the name of Etruria, that he first gave, after the old Italian state, where, as already mentioned, the art of pottery had been for ages carried on. And here we may remark how largely the success of a manufactory depends on cheap and quick means of transit. We have been told by an old inhabitant of Glasgow, that, about fifty years ago, the Clyde, at the lowest bridge near the Broomielaw, was scarcely deep enough to float a fishing-smack. Another gentleman informs us, that at that period, and being a boy, he used to go to see a little steam-engine, working at Tod and Macgregor's, then a small firm of smiths. At the present day, the Clyde has been so deepened that it will float the largest vessels, many, or perhaps most of which, now traversing the ocean to all countries, so far as iron is concerned as a material, have been built on the banks of that river by firms, who, from small beginnings, have arrived at the employment each of from 1,200 to 2,000 hands. For some miles down the Clyde, its banks are one continued scene of activity in ship-building and engineering. Manchester, again, has largely depended for its prosperity on the formation of the Bridgewater canal, carried out, like the Grand Trunk, by the celebrated Brindley; and, as we have just noticed, the pottery district of Staffordshire had its trade first developed by this canal affording cheap, and, for that time, ready access to distant large towns.

The Potteries is a term applied to a district of Staffordshire, embracing many towns and villages, where the making of all kinds of earthenware is extensively carried on. Stoke-on-Trent is a kind of focus of these places, which include Burslem, Hanley, Tunstall, Shelton, Fenton, &c. At the last census, it was estimated that at least 40,000 persons, male and female, were engaged in the Potteries in connection with this manufacture. Etruria stands a little out of the main road, through the Potteries; and in this district almost every kind of pottery is produced, from the finest porcelain to the coarsest brown or yellow earthenware. The whole district is abundantly supplied by adjacent coal-pits; consequently, the fuel which is so largely required by the potter is exceedingly cheap, and readily procured. We shall trace the history of the Worcester Porcelain Works at a subsequent page.

It is rather remarkable, that although plenty of clay is found in Staffordshire generally, it is not used to any extent in the Potteries, which get the supply of flints from Kent, and the clay from fine beds in Cornwall, Dorset, and Devonshire. But of this we shall have to speak more fully when we describe the materials of the potter.

The establishment of a large pottery rarely presents any external appearance other than that of a pure business character. The machinery in it is by no means delicate, like that used in engineering, cotton-spinning, or similar trades. As we shall see when we enter on a description of the practical part of the business, the machines required are of a comparatively rude or heavy character. Thus the flints require calcining, powdering, and grinding, so as to reduce them to an impalpable powder; this being effected by means of revolving cylindrical edge-stones many tons in weight. The materials are mixed together in a manner the type of

* *The Life of Josiah Wedgwood;* by Eliza Meteyard: 1866. Hurst and Blackett, London.

which may be seen in the brick-field; but, of course, in the pottery better machinery is employed, and steam is used generally in place of horse-power. The potter's wheel has scarcely varied from the early days of the Egyptians; and is really nothing but a lathe on which turning is performed perpendicularly, instead of horizontally, as in the lathe employed in connection with the production of machinery generally. Sir J. Wilkinson considers that, from Egyptian sculptures now in preservation, the date of its invention cannot be later than before the arrival of Joseph in Egypt.

The celebrated Dr. Kitto makes the following interesting remarks on the potter's wheel, as spoken of by Jeremiah (c. xviii., v. 3):—" 'Then I went down to the potter's house, and behold he wrought a work on the wheels.' The original word, rendered 'wheels,' is literally stones, and so the seventy have it in the present text. In Exodus (c. i., v. 16), the same is rendered 'stools;' and so, or rather seats, the Arabic and some other versions have here. But the Chaldee, Syriac, and Vulgate have 'wheels,' as in our version. There is no question that 'stones' is the *literal* meaning; and we incline to think that the potter's wheel is really intended, and that it is called a stone either because it was made of stone, or because its horizontal rotatory motion resembled that of the upper millstone.* Some interpreters have been induced to reject the 'wheel' interpretation, because Jeremiah lived before Anacharsis, who is said to have invented the potter's wheel. Such a reason has *now* little weight, particularly as the paintings of the ancient Egyptians, who were famous for their potteries [see *ante*, p. 523], show the same wheel in operation, the use of which is still retained in that country [see the preceding cut]. It will be seen that, as in common, it consists of an horizontal wheel fixed on the top of a stake, the lower part of which falls into a pit, in which stands the potter, who gives the necessary motion to the wheel with his feet, while he works the clay with his hand."

* See cut of ancient Corn Mill at p. 511, Fig. 371, *ante*.

It is a remarkable circumstance, that, despite all the great improvements of modern machinery, the potter's wheel has all but escaped modification. But the reason of this will be at once understood when we describe the use of the wheel; for we shall find that it is, even in the most primitive form, depended and constructed on a universal law of nature in revolving bodies—namely, centrifugal force.

With the exception of a turning-lathe, the preceding are the chief forms of machinery employed in the pottery. The kiln in which the work is baked, and the various departments in which each successive operation is carried on, together with other details, will come under full notice as we proceed.

Fig. 383.—The Egyptian Potter's Wheel.

Materials of the Potter.—First in order, the clay must be described; and it may be remarked that the kinds of clay are very various. That used in the neighbourhood of London for making bricks, tiles, chimney - pots, &c., contains silica, alumina, oxide of iron, sulphate of lime, or plaster of Paris, and other constituents of minor importance. Its deep red colour is due to its containing an oxide of iron—the peroxide. The presence of this latter is a matter of no importance whatever in coarse work; but, for the finest ware, it would not only be objectionable, but entirely unfit the clay for such purposes, because the object in making fine ware is to produce articles perfectly white, to be afterwards ornamented, wholly or in part, by colours laid on the white ground, and burnt in, so as to render them permanent.

It is hence a matter of the highest importance to the fine potter to obtain a clay that, on being fired—that is, exposed to heat in the kiln—shall not come out with any tinge of colour whatever except a pure white. But there is another point also of high importance. We have stated that clay is composed of silica and

FRAGMENTS OF ROMAN POTTERY, DUG UP IN LONDON.

ROMAN-BRITISH EARTHEN VESSELS.

GLASS VESSELS, FROM POMPEII.

ANCIENT POTTERY.

alumina, and it is so in the form of what chemists term a silicate of alumina—that is, silica, the pure matter of flint, quartz, &c., is an acid called the silicic; whilst alumina, the oxide of aluminium, is a base, and, by the union of the acid with the base, the silicate is formed.

Now, silica and alumina, together or separately, in a *pure* state, are the most infusible substance known in chemistry. They defy all ordinary heat—even that of the smith's forge—the oxy-hydrogen blowpipe flame only having any action on them. It is this property that is of the highest value to the potter; for he requires such a material as shall be absolutely incapable of fusion; because, the moment such fusion takes place, his ware ceases to be pottery, and is converted into glass. On the other hand, this absolutely pure clay, or flint, can be readily made fusible. For example, if some flints are first heated red-hot, and then plunged into cold water, they become friable, and may be easily reduced to powder. If this powder be mixed with three or four times its weight of carbonate of potash, or soda, and exposed for a couple of hours in a crucible, even in an ordinary kitchen fire, the silica of the flint will be melted, and may be poured out in a liquid form. The best potter's clay, or any other, if similarly treated, will give the same results. Hence the absolutely infusible silica, alumina, or the clay as silicate of alumina, may, by admixture with other substances, but especially metallic oxides, become as fusible as common glass, which will melt in a candle-flame.

Our unpractical readers, who have perused the preceding statement of the science of clay, will understand it still better by examining a brick-kiln after it has become cooled down. If the firing has been carefully conducted, the greater portion of the bricks may be readily separated from each other by merely removing them by the hand. But in some parts, in all brick-kilns, and where bad or careless firing, permitting excess of heat, has occurred, in all such kilns the bricks run together in one solid mass, as will be noticed.

Now this occurs because the clay of such bricks has contained oxide of iron, and other constituents, that rendered the silicate of alumina impure. These impurities act like the flux of potash, or soda, before noticed; and if the potter uses such materials, even if perfectly white, for his fine work, instead of being able to take out the cups, vases, &c., from the kiln as he found them, he would find nothing but a shapeless mass of fused clay, instead of the articles in a dry, hard, but rough condition.

And here, parenthetically (for we shall have to deal with the question in full detail hereafter), we may notice that the art of glazing depends on bringing the surface of all porcelain vessels into a kind of fusion; in fact, in really producing an artificial glass on their surface. This is easily affected by employing substances that have a similar action to the oxide of iron, in clay, brick, or to that of salt; the glazing powers of which we described at p. 526, *ante*, as having been accidentally discovered by a servant.

The possession of this pure clay by the Chinese in great abundance, and of which they have two varieties, called *Kaolin* and *Pe-tunt-se*, has, without doubt, been the reason why they have so long been able to produce the finest kind of ware in such perfection. We have already mentioned the Jesuit missionary, D'Entrecolles, at p. 524, *ante*, as having been long resident in China, and who paid great attention to every branch of the art of porcelain carried on in his time. It was to him that European potters were indebted for first finding out the nature of the materials used in China. He procured specimens of the two earths already named, and forwarded them to France. Reaumur communicated to the Academy of Sciences, about the year 1727, an account of his researches. He examined Chinese and Dresden specimens, and compared them with the best that France could produce; he broke them, burnt them, analysed them, and tested them in various ways; he procured specimens of the two kinds of earth used by the Chinese, the kaolin and petun-tse, and tried them separately by the heat of a furnace; he decided on what peculiar properties each kind derived its value; and in a short time afterwards, it was discovered that there were in France varieties of clay or earth which, if not identical with those of China, approached sufficiently near to answer the same object. A manufactory was established, under royal patronage, at Sèvres; and at this place specimens of porcelain were produced, which still rank amongst the finest known.

We may here mention the combined geological and chemical characters of this clay. Amongst igneous rocks, granite is extremely abundant. It contains felspar; and this, by the gradual action of air and moisture, becomes decomposed. The mass, at one time a type of solidity, and well known as a common material for bridges, large buildings, &c., at the present day, gradually crumbles down, and thus a very pure clay, or silicate of alumina, is formed, having as its constitution about sixty parts of silica, and forty of alumina.

Now, in our own country, none of this was known to exist until about the year 1765. The following is an account extracted from the report of the Commissioners of our Exhibition in 1851:—"The Cornish clay is the best [compared with those of Devon and Dorset], and is technically termed, by potters, 'China clay.' It is the decomposed felspar of the granite, and is prepared by the clay-merchants themselves in Cornwall prior to its being sent to the Potteries. Huge masses of white granite abound in Cornwall, which is in some parts found partially decomposed; and when this is the case, the mineral is raised and prepared for the potter's use, it having been discovered by Mr. Cookworthy, of Plymouth, in 1765, that it furnished the true *kaolin*, and also the *pe-tun-tse* of the Chinese.

"The following is the method of preparation:—The stone having been broken up by a pickaxe, is laid in a stream of running water; the light argillaceous parts are thus washed off,

and kept in suspension; the quartz and mica being separated, are allowed to subside near the place where the stone was first raised. At the end of these rivulets are a kind of catch-pools, where the water is at last arrested, and time allowed for the pure clay, with which it is charged, to form a deposit, which being effected, the water is drawn off. The clay is then dug up in square blocks, and placed upon a number of small shelves called 'linnees,' so fitted as to allow a free circulation of air, in order that the clay may be properly dried. Thus prepared it is extremely white, and, when crushed, forms an impalpable powder. It is forwarded to the Potteries under the name of China clay."

We have already noticed that Dorsetshire and Devonshire produce large quantities of the clay, and other sources have also been found in our islands; but none excelling, or perhaps equalling, the Cornish kind. A peculiar kind of clay, the result of the decomposition of a special variety of granite, or rather of the felspar of that granite, called China-stone, is obtained in Cornwall, and the whole produce of the county is sent to Staffordshire, where it is ground, and formed into a valuable glaze for the finest kinds of porcelain ware. The annual value of this article thus sent from Cornwall is very large.

Next in importance to the clay are flints and bone. On the latter we need make no remark, for the source is obvious. It much helps in giving a transparent appearance to the porcelain. In respect to the flint, it may be observed that it serves to give a glass-like appearance to the porcelain. The chalk deposit of Kent abundantly supplies this article. There are large lime-kilns in which the chalk is converted by calcination into lime, for building, farming, and other purposes. The flints are picked out, placed in a truck, and run on a tramway from the chalk quarry to barges or ships lying alongside, and so transported to their destination. The neighbourhood of Gravesend, especially near Rosherville, produces a large quantity of flint for the potter's purpose.

The flints, of course, require being reduced to powder. This is effected by first calcining them in a kiln, by which a peculiar molecular change is induced. In other words, the practical effect of this calcination is to convert the black flint into a white friable mass. Here we may notice, that although the exterior of a flint stone is of a white colour, it must not be supposed that the white is derived from the chalk whence the stone was taken. On the contrary, the chalk may be perfectly removed by hydrochloric, or any other strong acid, and yet the white colour will remain. The white on the surface is really silica in a finely-divided state, just as it may be procured by adding an acid to the solution of silica, already named as produced by fusing it with potash or soda. On dissolving the mass by water, when cool, out of the crucible, adding hydrochloric acid, the silica will be precipitated in a form somewhat resembling calf's-foot jelly. But, on drying this, the earth is produced as a white gritty powder; and it is just in this condition that the silica is found on the exterior of the common flint. Any of the upper cretaceous beds equally afford flints with those of Kent; but boulder flints are generally preferred.

The flint, after being so heated, is put into a mill somewhat resembling that used in forcing or stamping out oil from linseed, or other seeds. The following cut represents such a mill in operation, the workman feeding it with flints. It consists of logs of wood, shod with iron, which are raised by cams, or teeth-wheels, and allowed to fall with great force by their own gravity on the flints. A kind of grid or grating sifts the pounded mass from large fragments, and the latter are then transferred to a mill, and ground to an impalpable powder with water, affording a mixture having a density like that of cream.

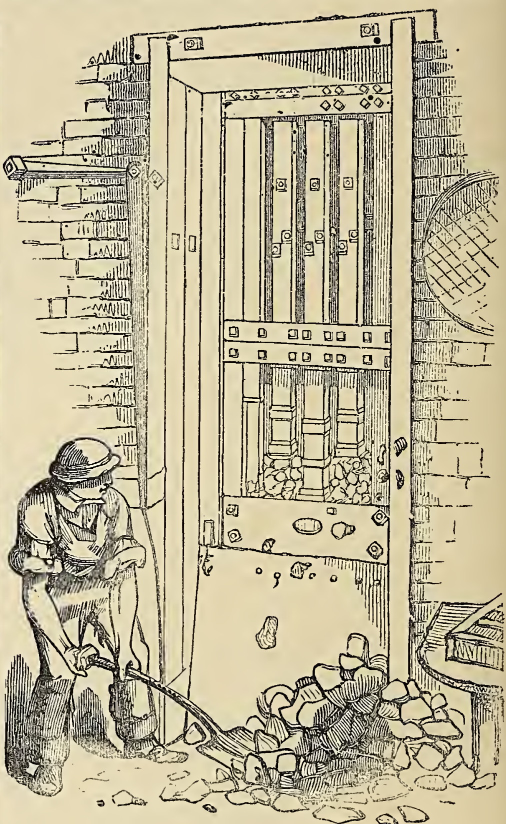


Fig. 384.—Flint-crushing Machine.

Sulphate of lime, or plaster of Paris, used for the moulds, is too well known to our readers to require any description. Usually it is found in the state of a crystal, of which the mineral *selenite* is an example. In this form, being first broken to pieces, it is then calcined, to drive off all water of crystallisation, when it becomes a fine powder, having a great attraction for water; and if, in the fresh state—that is, shortly after calcining—it be mixed with that liquid, it soon becomes quite solid. Hence the manufacture of the plaster casts, busts, &c., so commonly sold in the shops and streets.

It may be here observed, that large proportions of the clay, at all events in the south of England, such as is used to make bricks, contain much sulphate of lime. The London clay, in the north of the metropolis, possesses it largely, and it may readily be picked out in considerable sized crystals. Some time ago, requiring a material to form the bed of some garden-work, we purchased a quantity of fresh-burnt clay; that is, clay which, after mixture with coals, had undergone calcination. After being laid down in the walks, and exposed for some weeks to rain and sun, we were at first surprised to find that the whole surface glistened as with diamonds when wet and in sunshine. On close examination, it was found that the calcined sulphate of lime, gypsum, or plaster of Paris, had recrystallised, and had so produced this effect.

Various forms of mills are used for grinding flint and clay for the potter's purpose. One of them is illustrated in the following cut, in which

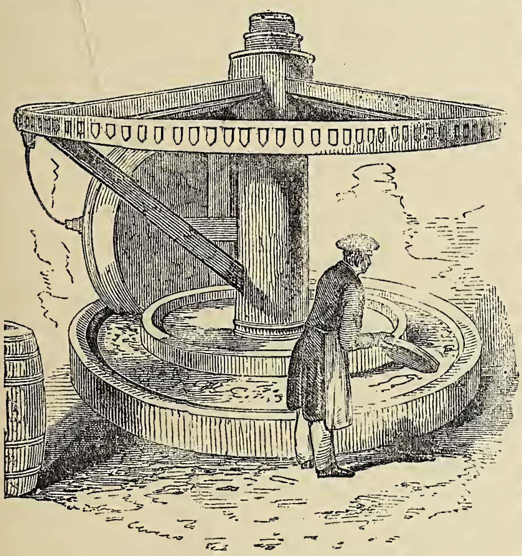


Fig. 385.—Flint and Clay Grinding.

an edge-runner of hard stone is represented as revolving in a trough containing the materials and water.

The reduction of the whole of the materials to the finest possible state of comminution, or division, is preparatory to that of what is technically called "slip-making," slip being the creamy substance arising from the preceding operation of bringing all the materials into a cream-like consistence. In fact, the slip is analogous to the pulp of the paper-maker, and the mode of producing each has certain points of analogy. In either case the object to be attained is to reduce the material into a condition in which solid matter, as nearly as possible, approaches that of the condition of the particles of a fluid; and the more completely this is attained, the more durable must be the article manufactured into pottery ware.

The choice of material, and the proportion of the mixture, necessarily depend on the article to be manufactured, and incidentally to the whims, caprice, or judgment of the manufacturer; and herein consists one of the secrets of the trade. The finishing of the slip is conducted in what is called the "slip-house," a detached building, one storey high, with the tiles of the roof placed apart, so as to allow of the escape of steam. The slip-kiln is shaped like a brewer's cooling-back. Its object is to evaporate off the superfluous moisture of the slip; but, where fuel is scarce, this is often done by exposing the mixture to the evaporating power of the sun's rays. With us, the slip-kiln, subject to certain modifications, is a long trough, or evaporating vessel, formed of particular-shaped bricks. The long bricks forming the trough rest on ranges of single common fire-bricks, laid so as to form separate flues for the heat during the whole length of the trough, which is from fifty to sixty feet long, about six or eight feet wide, and about eighteen inches deep. Here the materials of the slip become again solid, and a plastic material is produced for the potter's use; requiring, however, some preparatory processes to give it complete homogeneity.

The clay taken from the slip-kiln contains vacuous places filled with air; and if it were used in this condition blisters would form in the ware made from it. Formerly, to prevent this, the mass was cut up into wedges, and these were constantly dabbed with force against each other, at frequent intervals, for some months. But now this is effected by a kind of cutting machinery, in which knives are caused to revolve, and hence a great degree of homogeneity is given to the clay.

For the very finest sorts of ware every precaution is taken to keep out the slightest grit or dirt coarser than the material employed; and, whilst in the state of "slip," filtration is had recourse to, so as to remove any such particles. In fact, as already pointed out, next to good material, or clay, &c., the finest possible division of the particles is absolutely necessary. To make the clay as perfect as possible for the potter's purpose, it is said that, in China, it is prepared fifteen or twenty years before use; and during the whole of that period it undergoes repeated mechanical processes to make it of as even a texture as possible.

Presuming the material to be completely mixed, and of perfectly even texture, it is now ready for the throwing-room, or, in other words, it becomes suitable for the potter's wheel. It seems difficult to account, at first sight, for the term "throwing" being applied to an operation that has no relation whatever to the ordinary acceptation of that name; but it must be remembered that "throw" is a term locally applied, in Macclesfield, Leek, Derby, &c., to the act of doubling silk; hence "two throws," and "three throws," &c., are applied to that material in the thread, consisting of two or three threads twisted together. It is impossible, however, for a stranger to understand, still less to appreciate, the peculiarities that characterise the vernacular in Staffordshire, Cheshire, Lanca-

shire, and Yorkshire. About forty years ago, and when quite a lad, we first visited Oldham, in Lancashire, before the railway had been extended from Manchester into the town, and when that place had by no means got beyond the most primitive simplicity, not to say rudeness, of manner in its inhabitants. Desirous of visiting a mill there, we were fortified by an eminent Manchester firm with an introduction to the principal. For three weary hours, in a snow-storm, we vainly endeavoured to find the locality of the mill by asking for the name of the owner—not one person knowing the individual by name. At last, a young girl, by some powerful exercise of memory, discovered that we should not have asked for the spinner by his real name, but should have inquired for "Bill i' th' mouse-trap;" and this proved at once a guide to what we had long sought for: every one knew both the man and the mill by this term.

We have already alluded, at p. 528, *ante*, to the antiquity of the potter's wheel; and one of ancient form, as used for ages in Egypt, is illustrated at that page by Fig. 383. The modern "potter's wheel" is simply a stand, driven by a band from a large wheel; the stand varying from six inches and upwards in diameter. On it is placed a mass of moistened clay, before which the potter stands or sits. He is attended by two boys, one of whom, the "wheel-turner," causes the large wheel to revolve, and so gives rapid motion to the stand holding the clay; and the other, "the ball-maker," supplies the clay to the potter or "thrower."

Nothing is more simple in appearance than the act of "throwing," or fashioning the clay into various kinds of vessels; but it requires great tact to do this successfully. Under the direction of a clever operator, from Messrs. Doulton, of Lambeth, we succeeded, after considerable practice, in forming ginger-beer and blacking bottles, jugs, and vases, some years ago; but found that although clay may be pliant in the hands of any one, it requires a good potter to make that pliancy available as a means of livelihood, that we only took up for amusement. Perhaps our unpractical readers may better understand the method of throwing, if we describe it as we personally learnt it, under the circumstances just named; and we shall, therefore, do so in as familiar a manner as possible.

The clay ready for the wheel has a consistency somewhat similar to that of dough, used for pastry purposes; but it is more tenacious, and considerably firmer to the touch. All depends on it being properly "tempered;" that is, in having a right degree of moisture. If too moist it will not have sufficient tenacity to support its own weight, and if an attempt be made to make a bottle or jug from such materials, the sides of the vessel will collapse at the moment the wheel stops, and the labour of throwing will be lost. If, on the other hand, the clay be too stiff, it will not work "comfortably;" that is, its adhesive power will hinder, or even prevent the fashioning of any object out of it.

The clay, if rightly tempered, is first dabbed forcibly on the horizontal stand, so as to make it adhere thereto. The wheel-turner now turns his large wheel, and causes the stand to revolve with the clay on its surface. The potter or thrower, moistening his hands with water, now presses the sides of the moist clay, and forcing it upwards, it assumes the form of a solid cylinder, the height and thickness of which is determined by the thrower. To remove all air-bubbles, and to make the mass homogeneous, he presses the cylinder again into a flattish lump, repeating this until he considers that the clay is fully worked, so as to be free from every possible fault. Meanwhile the experienced hand can judge whether the clay is too moist or dry; and, according to either case, he adds some dry clay, powder, or water, so as to temper it.

The cylinder is again formed after the manner just described; and it is hollowed out whilst rapidly revolving, by pressing in the thumb so as to make it hollow. This having been effected, the thumbs and fingers are dexterously used, until a hollow cylinder—say of the shape of the ordinary gallipot—is formed. The thickness of the sides is, of course, under complete control; and, by the simple operation that we have described, we may suppose a plain jar, or pot of the kind just named, has been produced. Its inside and outside may then be rendered perfectly smooth by just holding a piece of bar iron or hoop against either; and the jar has then to be removed for drying, baking, and glazing.

We will next suppose the case of a blacking or ginger-beer bottle. The process is precisely similar up to the point that we have just left off, except that the vessel has less diameter. The neck of either is formed by pressing in the top of the cylinder by the hands until the required shape has been arrived at; and in the case of the ginger-beer bottle, which has a rimmed neck, a small piece of clay is dexterously slipped round the neck, and shaped with a piece of iron hoop into the form of the rim of the neck.

The rapidity with which these operations are performed by a practised hand is little short of marvellous. When carried out before a public audience the effect is almost bordering on the ludicrous; for, before the sharpest unpractised eye can detect the course or detail of the transformation, a jar, bottle, vase, and jug (except the handle to the latter, the making of which requires a separate operation), are readily, and almost as if by magic, produced by the thrower.

The scientific principles involved in the operation are readily explained. The turning of the stand rapidly tends to cause all the particles of the moist clay to fly off, by centrifugal force, in every direction from the centre of the mass. If the wheel be turned slowly this force is only trifling, and hence the mass of the clay is but slowly expanded. If, on the other hand, the wheel be turned rapidly, the particles of the clay acquire a greater disposition to fly off. The duty of the potter, or thrower, is to modify this centrifugal tendency; and, by doing this with judgment and dexterity, he can fashion any

circular-formed vessel with the most perfect ease, from the bottle or basin to the vase or ewer.

A vase, formed as above, is quickly converted into a jug, without a handle, by opening out one side of the rim with the hand, or a piece of iron hoop, in a manner that will at once suggest itself to our readers. The handle is made by rolling out a strip of clay to the required thickness. It is then bent into the form of a handle, and each of its extremities being moistened, are applied to the side of the handless jug. They quickly adhere, and so the jug is completed.

In a similar way it is evident, that a vase made with a plain surface on the stand can be ornamented as desired. The ornaments are pressed out with a stamp or in moulds, and then transferred, like the handle just described, to the surface of the vase, to which they at once adhere. Of course, the beauty of the vase will depend on the perfection of the mould that produces the ornament; but the preparation of these is left to a person possessed of higher art than the thrower, whose business it is only to put them on at the proper place. In large and expensive works of art, of course, greater precautions are taken; but here we are only explaining the principles of the potter's art, so far as the early formation of any vessel is concerned.

The description that has thus been given is, of course, only relating to vessels of a very ordinary kind; but it fully illustrates all the various modifications that the potter's art involves in the simple fashioning of the vessels. From the simplicity of the process, we therefore cannot be surprised that rude kinds of pottery have been manufactured for ages, in all parts of the world, to make vessels for holding liquids, &c. Of course, the lower kinds of pottery are all but devoid of ornamentation; and, as such, call for the exercise of no skill on the part of the workman; but we have seen that, by the exercise of a little extra trouble, even the commonest object may be made more or less ornamental, at little or no expense.

For regular workmanship in the pottery, the thrower is provided with a variety of tools. He requires gauges, so that in making a number of similar vessels he shall have them all of one size. By means of "profiles," or "ribs," he can exactly curve or shape the inside or outside of any form of vessel, and remove all superfluous clay, rendering the object, as far as possible, of even size and substance in all parts—a matter of great importance in the subsequent operation of baking; when, if the thickness be uneven, the contraction, which is enormous, will be irregular, and a distortion of the work would arise. The waste clay, or rather what is removed from an object on the wheel, is technically called "slurry." Occasionally, the article, as a candlestick, door-handle, &c., is solid; but, from the extreme plasticity of the clay, it will be evident that there is scarcely any form, from the blacking-bottle to the copy of the most elaborate work of art or sculpture, that cannot be produced by skill, experience, and care. One of the most remarkable objects of the kind that has yet been produced, was the Majolica fountain, that attracted so much attention in the Exhibition at Hyde Park, London, in 1862. The magnificent chimney-piece, from the Royal Saxon China Manufactory, and many other similar objects, the memory of our readers will readily call to mind, as there shown.

Vessels, when they leave the potter's wheel, have, of course, a roughish exterior. This may be readily seen on the surface of an ordinary blacking-bottle, or any common circular article of pottery. The better class of articles are accordingly submitted to the lathe, as represented in the following cut. They are allowed to stand

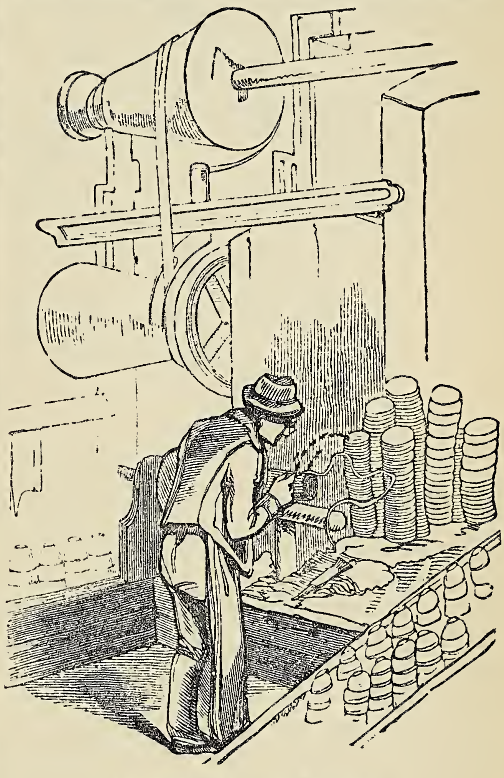


Fig. 386.—Pottery Turning.

until they have become apparently dry, and are then acted on by the lathe, much in the same manner as is adopted in ordinary wood-turning, and thus a clear exterior and regular shape are obtained.

The formation of flat objects, such as plates and dishes, is remarkably simple. The workman has before him a kind of stand, on the top of which is a flat wheel. On this is a reverse copy of the plate in plaster of Paris. A piece of clay is beaten or rolled out to the thickness nearly of the intended plate, and of about the same size. The clay is laid on the plaster cast, and the horizontal wheel is set in motion. The clay is pressed on to the mould during the act of rotation, and the bottom and edges of the intended plate are shaped at the same time, by

ribs, profiles, &c., as already explained; and thus the smooth underneath, or exterior of the plate, is produced. The process is represented in operation in the following figure.

Fig. 387.—Plate-making.

We have already roughly described the mode of putting on handles to jugs. The following cut will fully illustrate the method of "handling" cups, &c. Long strips of clay are formed of a circular or wire-like shape, by pressing the material through a brass tube, or mould, something after the fashion adopted in making macaroni. As much of one of these is cut off as will be long enough to form the handle. It is attached to the "green" cup—that is, the cup as it has come from the wheel—by first dipping each end into a little "slip" (see *ante*, p. 531), and is dexterously bent into the desired shape. The ready manner in which this is done by an "old hand," is really remarkable.

The processes that have been described are equally applicable to all kinds of ware, as regards the general principle, from the kitchen basin to the finest style of china, porcelain, or any other kind of ceramic work. A great variety of names has been applied to the numerous qualities that have been brought out of late years. As already noted, Wedgwood gave an impetus to the trade generally; but, further, he gave it the initiative of a new direction. Many modern varieties are imitations of those of classic days, as the coloured ceramic Majolica, derived from a corruption of the name of the island Majorca, in the Mediterranean, in which that variety of pottery was first established by the Spanish Saracens, who there brought it to great perfection. Parian ware is now largely used to make statuettes, vases, &c.; and some beautiful specimens of the kind have been produced by many eminent makers. The Worcester ware of this country has attained a remarkable degree of elegance, magnificent specimens of which were

Fig. 388.—Plate-making.

seen in the Exhibition of 1862, and, more recently, in the Paris and other Exhibitions. Beautiful as are the Parian figures, especially such as have been brought out by Alderman Copeland, they promise to be eclipsed by other materials that are less subject to contraction in the furnace, that bane of the manufacture of pottery; also to which we shall more fully allude hereafter when describing the operations of burning or firing in the kiln.

Abroad, Berlin, Dresden, or rather Meissen, Sèvres, &c., are all noted for the beauty and excellence of their various kinds of china ware. The ware sold as Berlin porcelain is an invaluable material for the vessels of the practical chemist. But we must forbear enlarging on these and other extensions of the art and practice of pottery, to return to practical considerations.

In respect to modelling objects for pottery ornamentation, it must be within the knowledge of all our readers that an immense deal has been done in recent years. The "willow" and "rose" patterns, barbarous and unmeaning in every possible respect, have given way to designs of the greatest beauty and excellence. Indeed, some specimens of modern pottery, in respect to the ornamentation of plates, vases, &c., vie in perfection with the best oil-colour productions of the art-painter. In the Exhibition of 1862,

some rich specimens of modern art of this kind were seen; as, for example, the service in china ware, executed for her majesty. The popularity and excellence of this form of pottery was evidenced to an extraordinary degree; for the porcelain courts were amongst the most frequented of any. So much so, indeed, that a satirical writer observed—"Noting all this excitement, it is not difficult to realise one of those great china crazes of the past, when some high and mighty personages became porcelain mad; and crowds of little people got porcelain mad also—that time, for instance, when Augustus of Saxony exchanged a regiment of dragoons for some old china vases; or the period when Charles, King of Naples, worked as a potter in his own palace, and had before the gates of that palace a shop, in which the productions of the royal manufactory were sold."

But, besides improvements in painted designs, the imitation of sculpture, fruit, flowers, &c., so as to place such in relief on the body of a vessel, has made wonderful progress. The Parian of Alderman Copeland has been already named. The various other articles of fine pottery, as vases, jugs, statuettes, &c., all indicate that the art of modelling has greatly advanced since the day when Wedgwood so successfully copied the Barberini, or Portland vase. This great progress may be chiefly considered as having arisen from the beneficial effects of the Schools of Design, now so largely spread in every branch of our manufacturing districts. Whatever natural taste a man may have, it rarely becomes of much practical value without that discipline of mind and hand that a regular course of instruction, under competent teachers, alone can afford. There is no department of education so backward in this country as that of a technical nature—that education which brings out inventive genius or artistic taste naturally existing in individuals, by teaching them what has been done by others, developing that which has a tendency to high art in themselves, and pointing out the way in which such efforts of genius can be best utilised by our manufactures. For example, we have before us some fine specimens of pencil china—a family relic, that, in our boyish days, were considered as admirable specimens of art, especially in the delineation of landscape. But, at this day, far finer specimens are commonly sold, in painted designs, at a mere fraction of the cost of those to which we have referred, and executed in a far superior style. On this point Mr. Porter justly observes—"The taste of the modeller is put in requisition; calling for the execution, on his part, of a high degree of skill and ingenuity in forming patterns, and adapting to them appropriate ornaments. To be a perfect modeller in the higher branches of the art, a man should have an acquaintance with the best productions of the classic climes of Greece and Rome; he should be master of a competent knowledge of the art of design; his fancy glowing with originality, tempered and guided by elegance and propriety of feeling, and restrained by correctness of taste and judgment. To a man thus gifted, the plastic and well-tempered material wherewith he works, offers little of difficulty in the execution of his conception."

The art of transferring colour to china we shall afterwards speak of more fully. The solid external ornaments affixed to china ware of all kinds, are either produced by the simple operation of the ribs or profiles already mentioned for coarse objects; by pressing tempered clay into a mould which contains the design hollowed out in it, and, of course, in reverse; and by casting—that is, by pouring the clay in a liquid or cream-like state. All such vessels as cannot, from the complexity of their figure, be turned on the lathe, are made by one of these methods, according to which is the most eligible. The moulds are generally made in plaster of Paris, after the usual mode adopted by the Italian modellers, and which is too well known to require description, and may be seen constantly in operation in most of our chief towns. The method of making large objects of porcelain statuary is thus effected:—"The clay, which is used in a semi-liquid state, about the consistency of cream, called slip [a term already explained at p. 531, *ante*], is poured into the moulds forming the various parts of the subject; sometimes these amount to fifty in number. The shrinking that occurs before these casts can be taken out of the moulds, which is caused by the absorbent nature of the plaster of which the mould is composed, is equal to a reduction of one inch and a-half in height in an object having a height of two feet. These casts are then put together by the figure-maker; the seams (consequent upon the marks caused by the sub-division of the moulds) are then carefully removed, and the whole worked upon to restore the cast to the same degree of finish as the original model. The work is then thoroughly dried, to be in a fit state for firing; for if put into the oven while damp, the sudden contraction consequent upon the great degree of heat instantaneously applied, would be very liable—in fact, almost certain—to cause it to crack. In this process it again suffers a loss of one inch and a-half by evaporation; and it is now but one foot nine inches in height. Again, in the firing of the bisque oven [of which we shall have to speak fully hereafter], its most severe ordeal, it is diminished three inches, and is then but eighteen inches high, being six inches, or one-fourth, less than the original. Now, as the contraction should equally affect every portion of the details of the work, in order to realise a faithful copy, and as, added to this contingency, are the risks in the oven of its being over-fired, by which it would be melted in a mass, and of being short-fired, by which its surface would be imperfect, it is readily evident that a series of difficulties present themselves which must require considerable practical experience successfully to meet."

Having thus described most of the processes which are adopted to form the clay into any desired article, we shall next consider how, by means of heat, such vessels are brought from the green or fresh state to a condition in which they are first biscuit ware; and, secondly, glazed

china. We shall afterwards describe the method of ornamentation by painting, &c.

Drying and Firing.—From the observations already made, our readers will gather that pottery of all kinds, on drying, greatly contracts in bulk. In fact, we have somewhat under-stated the average contraction in bulk, arising from the processes of drying and firing, as such contraction more nearly approaches a third rather than a fourth of the original.

After the form of the pottery is completed, it is carefully dried, so as to remove all moisture as far as can be possibly effected. If this was not well attended to, the pottery, on being introduced into the kiln, would most likely fly to pieces, owing to the expansive power of the water it contained in the process of conversion into steam. Such an effect as would thus arise is familiarly known in the bursting open of slates in coal in the domestic fireplace, attended, as that often is, by a somewhat powerful explosion, and ejection of the hard earth into the room.

Before being placed in the kiln, the articles of china ware, &c., are packed in a kind of vessel called a "seggar," a representation of which is seen in the following cut. The object of putting the articles into "seggars" is that of protecting them from the smoke, dust, &c., of the kiln or oven, the effect of which would be to completely discolour and spoil the ware.

Fig. 389.—Putting Pottery into Seggars.

Of course, the size and shape of the seggars depend on the peculiar character of the articles they are intended to hold. Occasionally a number of different or similar objects are enclosed in one seggar; whilst at other times a seggar will be made for the purpose of containing one object. If, however, a number of articles of the same or of different kinds are enclosed in one seggar, great care is taken to keep each separate, so as to prevent any possibility of their running together during the process of baking.

The term "biscuit" is employed to designate the burnt or fired ware; and the ovens or kilns in which the burning is effected are similarly denominated. A "biscuit kiln" is represented in the following cut; and in it will be

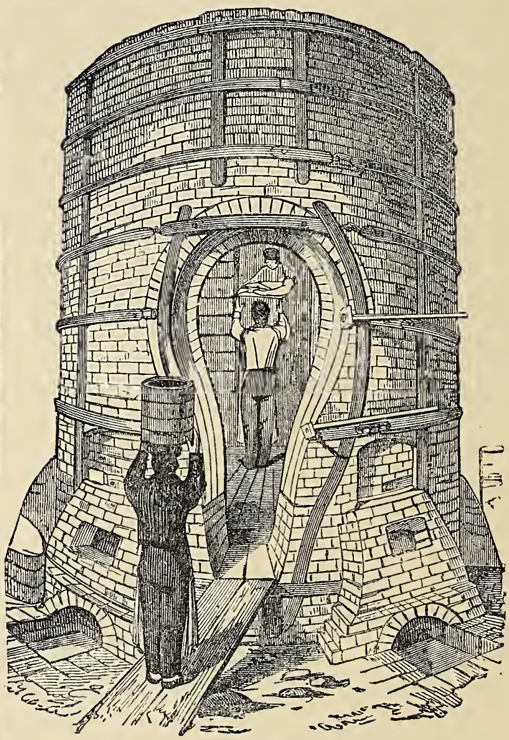


Fig. 390.—The Biscuit Kiln.

noticed the arrangement of the seggars, and externally are the furnaces that supply the heat to the kiln. Both the seggars, and, at least, the inside of the kiln, are formed of the most refractory fire-clay; for, of course, the heat to which the articles are exposed is exceedingly intense. The length of time during which the articles are subjected to the heat, of course, varies both in respect to their size and quantity. On an average it may be stated as from a day and a-half to two days (that is, twenty-four hours to the day).

The effect of the firing or baking process is to aggregate the particles of the clay into a condition but little short of, and yet not complete, fusion. Alumina (see *ante*, p. 529) has an enormous attraction for water; so much so, indeed, that at a heat at which iron melts it will retain that liquid in a state of chemical combination; but the application of intense heat gradually

brings the particles of the alumina and silica into a state of solidity little short of what can be effected by chemical action.

When the earthenware has cooled down, and is taken from the kiln, its exterior is quite devoid of polish. In fact, there is just as much difference between the "biscuit" and glazed porcelain, as there is between white blotting-paper and that usually called "cream-laid." In this condition the "clay" has parted with the large portion of the water with which it was previously combined; at the same time, it is, to a certain extent, porous, and quite unfit for domestic purposes.

From the various causes already explained—as, for example, contraction, irregularity of firing—the potter by no means can reckon on the whole of the articles that he has committed to the kiln, coming out in a condition that will permit of further operations. From all such causes, and others, loss is continually sustained. "A judicious fireman, aware of the contents of his oven, and the coals he is using, will judge tolerably well of the state of the baking merely by inspection, attentive practice enabling him to judge of the degrees of temperature; and he will keep up the high heat its requisite time, and produce excellent ware, often saving, in fuel, more than the amount paid for his labour. But when baking devolves on a less experienced or negligent fireman, he too frequently conducts the progress irregularly, and loss ensues; also from short firing of pieces placed in situations deficient of heat; for, if the heat be not sufficiently high and long-continued, the ware will be very fragile; and if it be too great, or be imperfectly continued after gaining the requisite high temperature, many of the articles will be fused into a shapeless vitrescent [glass-like] mass. Those bodies which do not flame when made red-hot by continued accession of heat, are without hydrogen, or want power to fix oxygen, so as, *per se*, to continue the heat. The silicious mass becomes red-hot, and continues so by constant heat, without producing chemical changes; whereas the fuel or coaly mass, when hot, evolves hydrogen gas, which, combining with oxygen, produces compounds, and feeds its own heat as long as the hydrogen gas is evolved, and the oxygen is fixed; and then the oxygen, no longer in gaseous motion by its condensation, becomes productive by radiating heat; and the process continues as long as any hydrogen is evolved by the heat of the fixed oxygen, and as any oxygen remains to be fixed.

"For the proper management of the baking, a very accurate acquaintance with the appearance and precise duration of the successive rises and degrees of temperature of the interior of the oven, viewed through the small holes in the cylinder, is indispensable to the fireman. He will gradually raise the oven and its contents from the commencement, adding fuel as the rarefied air circulates and evolves through the dome, the draught increasing till all is at a red heat: increased supplies of fuel raise a white heat, which is kept up for a certain number of hours; and then the mouths are stirred, and charged with fuel, for the firing up or highest rise of temperature to complete the baking, which, expelling from the components of flint ware and soft porcelain all moisture, without fusion—which would render the ware fragile and brittle—the biscuit ware is so agglutinated as to be properly hard, compact (porcelain semi-transparent) porcelain, completely vitrified, and the glaze perfectly vitrescent."

The glaze on the surface of all porcelain ware, from the lowest to the highest kind, and in all kinds of pottery, is simply the result of the production of a kind of glass on their surface, by coating the biscuit ware with a liquid of various composition, and subsequently exposing the ware to heat, to fuse and vitrify the glass. Common salt, and a small portion of oxide of lead, were, at one time, much used. But this has been almost entirely superseded by other glazes, of which there is a great variety. "When the ware has been baked biscuit, its dry appearance will suggest, and its bibulous nature, from the presence of alumina, on immersion in water, will demonstrate its porosity, inconvenient for many purposes of utility, and occasioning rapid destruction. This inconvenience has been understood by all manufacturers of earthen vessels; and the necessity, as well as utility, of a preservative covering, led to the employment of a glaze applied to the biscuit ware. It was requisite that its bibulous and permeable nature should imbibe the water of the mixture (glazing) readily, and leave the surface covered with a thin coating of components, readily drying into a solid shell of uniform thickness over all the parts, sufficiently hard not to be rubbed off, but remain permanent, while the vessels are being placed in seggars, kept asunder by cockspurs, stilts, triangles, &c.; while again exposed to the glaze-baking process at a white heat for many hours continued, of all inside the oven—bags, seggars, and their contents, by which the components, during fusion, incorporate with the surface; and at the completion of the process, that the ware should be covered with a perfect glass, promoting the durability, and improving the appearance."

The mixture for making the glaze being made, the vessels undergo a process technically called dipping. Much care is required that the glaze should spread equally over the surface; and neglect in this respect is often seen in its consequences, by great patches on the common kinds of earthenware. The vessels are then transferred to seggars, next to the glaze-kiln, and leave this in the condition familiarly known in all articles of glaze ware in ordinary domestic use.

When we describe the process of annealing glass, it will be seen that such is of the highest necessity for that article; or, in its absence, the glass will be liable to crack on any sudden increase or decrease of its temperature. In a lesser degree, the same holds good with earthenware; hence it is cooled down slowly, whether in biscuit-baking or glazing. The heat employed in each of these processes is exceedingly intense; indeed, perhaps but little inferior to that of the

smith's forge, which is about the highest afforded by any ordinary means of artificial heat, except that of the oxy-hydrogen flame, and the disruptive discharge of the voltaic battery.

At a previous page (see p. 535, *ante*), we have described the methods adopted in producing raised figures, as ornaments on the exterior of china ware, the production of statuettes, &c.; and to have maintained the proper order of procedure, we should have described the art of painting porcelain before the firing and glazing operations. But the question of painting has been deferred till last, in this account of pottery-making, because we have thus been enabled to keep up a continuity of description applicable to all kinds of pottery, painting only being adopted for special kinds and purposes; and being, consequently, a separate or individual process.

As a rule, metallic oxides are employed in all operations of colouring porcelain and glass; for, of course, the intense heat to which both of these materials have to be exposed to fix the colour, would make the use of any other kind of colouring material impossible. Amongst the metals so employed, or their oxides, are gold, silver, copper, iron, chromium, manganese, cobalt, &c.

Of course, the beauty and perfection of the design will greatly depend on the taste of the painter. As already noticed when speaking of modelling, some modern pottery presents views of landscapes, &c., &c., vyeing, in perfection and beauty, with the best oil paintings. Whilst our painted porcelain is made to imitate all the beauties of nature, the Chinese kind is generally grotesque, and often ludicrously so. On this Mr. Porter remarks—"In examining the painted porcelain of this singular people, one is almost led to imagine that their artists have been debarred the sight of the objects which they attempt to represent, as otherwise some amongst them must surely have possessed sufficient innate taste to have led them from the general track; and, instead of the miserable caricatures that disgrace their labours, to have made some approach towards the truth in their delineation of natural objects. * * * * One artist forms only coloured circles about the edges; another traces flowers, which a third paints; a fourth delineates nothing but mountains; a fifth describes water; a sixth traces the outline of birds, which a seventh fills with colours. Other artists trace and colour animals; others, again, perform the same tasks with the human figure; and in this way every object of art and nature found upon their porcelain, is the work of a particular artist, who does not attempt the delineation of any other subject. To this system, so useful in conducting every merely mechanical operation, may possibly be owing the continued adherence to old and faulty methods. The celerity which it is calculated to produce is unfriendly to the improvements suggested by genius; and if even one artist among the crowd should be found with taste enough to aim at forming and embodying juster conceptions, his approaches to nature would only serve to render more glaring the deformities produced by his fellow-labourers, and would therefore be wholly inadmissible."

Nevertheless, we cannot help giving the Chinese full credit for the vast amount of ingenuity that they display in every occupation of handicraft, apart from operations involving machinery. The following account of some of their methods of ornamenting porcelain, cannot be read without exciting interest:—"Besides the usual process of painting and gilding, the Chinese adopt curious methods of producing ornamental porcelain. One is a sort of magic porcelain, in which the colours and devices appear only when the vessel is full of water. In making these, the first requisite is that the vessel shall be extremely thin. After the baking, the figures are painted on the inside; and when this painting is dry, a very thin coating is laid over it, formed of the same material of which the vessel was made, in a semi-liquid form; and a coating of varnish is applied over this. The picture is thus buried, as it were, between two layers of porcelain. The outside of the vessel is then ground down as close to the figures as possible, and then varnished. The vessel thus prepared is placed in an oven, and all the layers baked together. The colours chosen are of a very faint tint, so as to be scarcely, if at all, visible in the present state; but when the vessel is filled with water, the coloured device becomes visible from a difference of the play of light in and around the vessel. Another peculiar kind of porcelain made by this singular people, presents the appearance of having a raised device, although the surface is quite smooth. To produce this, a very thin and fine porcelain cup is made in the usual way, and well smoothed inside and out; but before it is baked, and while the clay is yet damp, a stamp, cut in relief, is pressed upon the inner surface of the cup. Very fine white varnish is next applied copiously over both surfaces, so as to fill up the cavities where the impression was produced by the die. By this means both surfaces are rendered smooth and regular again; but on holding up the cup before a light, the device will appear with much effect, since the parts where there is a great thickness of varnish, and a small thickness of porcelain, will present a different tint from those parts where the opposite conditions occur."

To enter on an extended description of the various methods employed in this country, would far extend our subject beyond its limits. Except in certain details, the mode of painting china differs but little from that adopted in miniature painting, and other similar methods of ornamenting ivory, &c. The colours, already stated to be metallic oxides, are ground up, with oil and fine turpentine, into a paste. By means of camel-hair pencils, the colours are then laid on the ware. The latter is next placed in an enamel furnace or kiln, where the heat to which it is exposed is sufficient to fix the colours, and vitrify them on the porcelain. Of course, great care is requisite in this operation, or otherwise the colours would run altogether. The painting is done, at times, on the biscuit ware, and at

others after glazing, according to the purpose or subject chosen.

Blue printing is carried on after a different method. Without entering into the full details of a process the results of which are gradually going out of public favour—although, at one time, almost the only ordinary form of coloured ware of an ornamental character—the following may be taken as an outline of the method adopted :—A pattern is first drawn upon paper, according to the size and shape of the vessel to be printed. The pattern is next engraved on copper. This plate is then employed much in the same way as in ordinary copper-plate printing. The printer holds it over a stove, and then fills up the engraved portion with a kind

Fig. 391.—Printing Blue-ware.

of blue paint, that will retain that colour after exposure to heat. The plate is then rubbed clean, and on its surface is placed a peculiar tough kind of paper. The plate and paper are then passed through a press, as represented in Fig. 391. The paper has thus transferred to its surface the engraving on the copper. A female attendant cuts it to the shape and size of the vessel, and (Fig. 392) transfers the engraving to the unglazed surface of the plate. Pressure is employed to cause as much deposit of the paint as possible. The paper is then removed by dipping the plate into a vessel of water, when the pattern will be seen on the surface of the plate, which is then exposed to heat in a kiln, and glazed. Of course, any colour may be produced by employing such metallic oxides as will produce any chosen one after firing.

There are many other methods adopted, which we cannot stay to detail. Gilding is effected in a similar manner to the painting, the gold being

Fig. 392.—Printing Blue-ware.

first ground up, as is done with colours. It is then laid on with a camel-hair brush; and by firing and burnishing, its natural metallic appearance is restored. The chlorides of gold and tin, on being mixed together in equivalent proportions, afford the rich purple colour often seen on china, and known technically as the purple of Cassius.

One department of the art of pottery that has become highly popular of late years, is that of making ornamental tiles. In this manufacture, Messrs. Minton have produced some beautiful kinds for forming floors of halls, public buildings, and other places. In the Houses of Parliament, Westminster, floors, &c., thus formed, and of the most beautiful and expensive devices, may be seen. But their use is becoming exceedingly general, especially in places over which there is much traffic—as, for example, the entrance of hotels.

These tiles are formed of different coloured clays, the union of which produces the design; there being generally a ground colour, which is commonly of a reddish-brown tint. Various methods have been invented for making them; but as the details are of a purely mechanical nature, we need not enter into the full discussion. One of the most ingenious methods is that of Mr. Prosser, of Birmingham. By this plan the clay is reduced to powder, and compressed between steel surfaces. It is thus condensed into about a fourth of its original bulk,

and becomes a solid, compact, and hard substance. The method was at first confined to the manufacture of porcelain buttons, but now is largely adopted in making tesseræ for ornamental pavement.

It would be impossible here to enter into a description of all the varieties of quality that the best and common clays produce, of vessels in the potter's hands. With most of these our readers will be familiar; and the general principles of their manufacture, from the common draining tile, domestic pots and pans, terra-cottas, &c., &c., to the highest style of pottery, are identical in most respects, and have been noticed in the preceding pages.

For similar reasons, any lengthened notice of the manufacture of bricks may be omitted. At the early portion of this chapter, we have entered into some interesting particulars of the history of brick-making. At present, the brick-field is, unfortunately, a constant appendage to the skirts of most of our large towns, which are gradually expanding over field after field, the clay of which, in many cases, leaves its old site

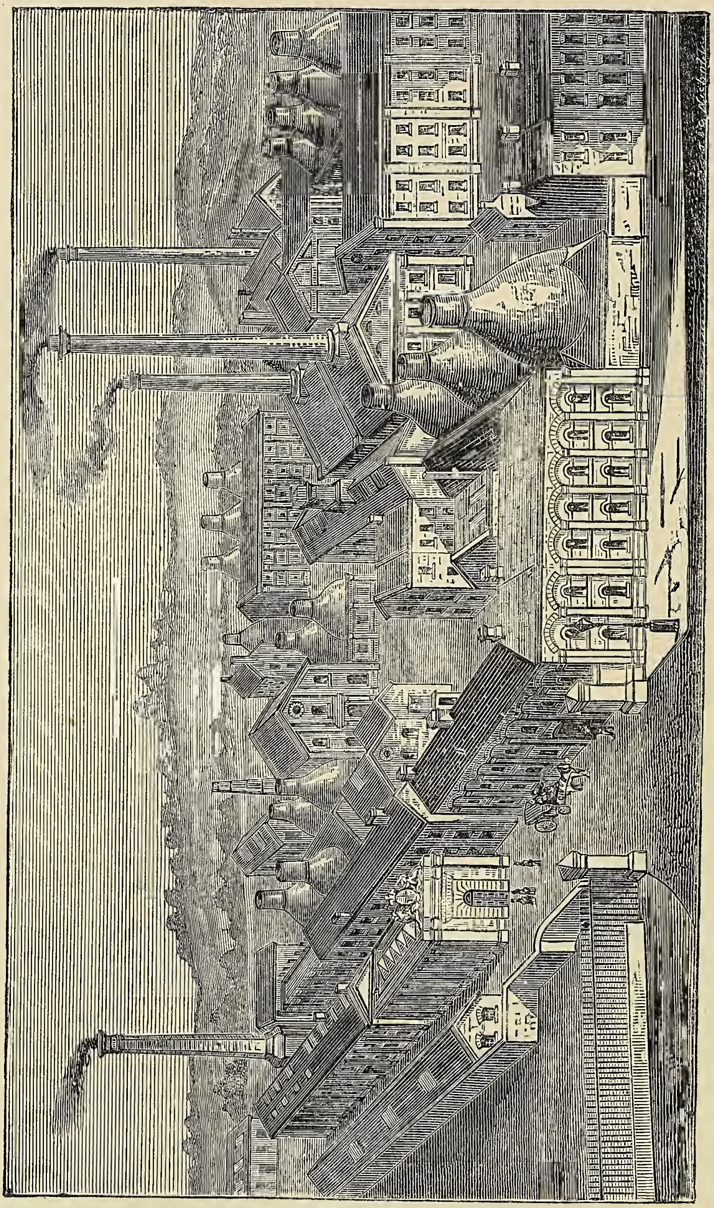


Fig. 393.—The Worcestershire Royal Porcelain Works.

below, to form new buildings above. The application of machinery in the making of bricks, tiles, &c., is now exceedingly common, whilst the demand for them has made the manufacture one of the highest importance. Of course, in many parts of our islands, stone is really cheaper, as a material for building construction, than bricks.

The most important manufactory of pottery of an ornamental character, carried on in this country, is that of the Worcester Royal Porcelain Works, which, in many respects, are certainly not exceeded, if equalled, in regard to their productions by other works in Europe. We have been favoured by the proprietors with a general and detailed account of the varieties they make, which include the following, together with the history of the works.

Varieties of pottery produced at Worcester:—

- Fine porcelain.
- Ivory porcelain, a speciality.
- Vitreous stone ware (semi-porcelain), a speciality.
- Crown ware (superior earthenware), a speciality).
- Parian.
- Majolica.
- Terra-cotta, &c., &c.

The raw materials consist of—

China clay,	from	Cornwall.
China stone	,,	Cornwall.
Felspar	,,	Sweden.
Fireclay	,,	Stourbridge.
Do.	,,	Broseley.
Marl	,,	Broseley.
Flint	,,	Dieppe and Gravesend.

Calcined bones, both home and American.

All of these have been already dealt with under the head of "Materials of the Potter," at pp. 529—531, *ante*.

The styles of decoration in use at the Royal Porcelain Works embrace all those usual on pottery and porcelain. The following are specialities more or less peculiar to these Works:—

- Perforated Porcelain.
- Ivory Porcelain.
- Raphaelesque Decoration.
- Bronze and Metallic Decoration, in various styles.
- Jewelled Porcelain.
- Enamels on Royal Blue (Worcester enamels).
- Modelled and Coloured Golds, as exhibited at Paris in 1878.

The Worcester Porcelain Works were established in the year 1751. The staple manufactures of the city had been for some years declining; the cloth business had been driven away by unsatisfactory trading; carpets and gloves were still made, but did not afford sufficient occupation for the people; and it was also considered advisable to raise up, by extended manufactures, a body of workmen who should be freemen electors, trained to withstand the Jacobite tendency of the time.

The manufacture of Porcelain was engaging the attention of the Princes of Europe, it was enjoying a reputation in England at Bow and Chelsea, and its artistic and scientific labours were such as to enlist the sympathies of every one desirous of improving the trade of the country and the tastes of the people.

Worcester had neither coals, nor clay, nor skilled hands, but "the faithful city" had Dr. Wall, a talented physician, a clever chemist, and an accomplished artist. By his scientific skill he produced one of the most beautiful porcelains in Europe—which is even now the admiration of connoisseurs—and to his judgment and enterprise the concern was indebted for the first thirty years of its success.

The Worcester Company made a fine porcelain from the commencement, and decorated it after the Chinese taste according to the prevailing models. The earliest designs were nearly all painted in blue. In 1756, transfer printing was introduced, both with finely-engraved black prints on the glaze and with blue prints under the glaze, which could with difficulty be distinguished from the painted subjects.

The styles adopted at Worcester were very varied, but were generally selected from the finest examples of Japanese and Chinese and Dresden manufacture, as well as the very beautiful wares of Sèvres and Chelsea; but whatever style was produced it was made to bear a Worcester character, and, with the exception of Chelsea, no English works bear evidence of so much loving care in their production. It is certain that from about 1760 to 1775 some extremely beautiful wares were produced, both in vases and services. The specimens which have lately been brought to light have never been excelled in England.

Doctor Wall died in 1776, and the remaining partners carried on the works with spirit and success until the year 1783, when the whole establishment was sold to Mr. Flight, of London. The business was conducted by his two sons, Joseph and John, till 1792. In 1788, George III. visited the Worcester works, and granted his warrant permitting the establishment henceforth to be called "Royal."

In 1793, Mr. Barr joined the concern, and the firm of Flight and Barr commenced. It continued without variation until 1807, when Mr. Barr, jun., was taken into partnership, and the title was altered to Barr, Flight and Barr, which lasted until 1813. On the death of Mr. Barr, sen., a younger son was taken into partnership, and the firm changed to Flight, Barr and Barr, which was continued till 1840, although Mr. Flight had died in 1829. The establishment was united to that of Messrs. Chamberlain in the former year (1840).

The united firms in 1840 were constituted a Joint Stock Company, and in 1862 commenced the present Joint Stock Company.

In the early part of the present century Worcester had few competitors in the manufacture of first-class porcelain. The patronage of the King and Royal Family, which was liberally accorded, stimulated the production of both fine porcelain and artistic productions. A special body, called Regent Porcelain, was invented by Mr. Chamberlain for the Prince Regent, and obtained great favour from the

Court; but being very costly in its production it was discontinued after a few years, other improved bodies taking its place, having equal durability of wear and beauty of appearance.

Messrs. Chamberlain entered largely into the manufacture of porcelain buttons made of dry clay by pressure, but a dispute about the patent in 1850, and the introduction of a similar article from France, put an end to the business.

The manufacture of encaustic tiles was also introduced by Messrs. Chamberlain. These had a great and deserved success. This business was transferred to Messrs. Maw in 1851, and by them shortly after removed to Broseley, where the establishment has been greatly extended, and obtained a very high position from the artistic character of its productions.

The second century of the Royal Porcelain Works commenced with a new proprietorship—Mr. Kerr, who had been a partner in the former firm with Mr. Chamberlain and Mr. Lilly, was now joined by Mr. Binns; the buildings of the manufactory were largely extended, and considerable progress was made in giving a higher tone to its productions, which received high praise at the Exhibitions of 1853, 1855, and 1862; in the latter year the business was formed into a Joint Stock Company, since which time further large additions have been made to the works, which now (1881) employ about 600 people, and increased reputation has attended their productions. The highest award (the Diploma of Honour) was obtained at Vienna and at Paris —the Gold Medal, and the Legion of Honour to the Managing Director.

Fig. 393 affords a representation of the Worcester Royal Porcelain Works, which has kindly been placed at our disposal by the Managing Director, R. W. Binns, Esq. But a subject of still greater interest to many of our readers will be the illustration of the marks on Worcester Porcelain. The proprietors state "that many of the best specimens are not marked, and a large number bearing marks of repute are of little value. It does not therefore follow that, because a piece is marked, it is of high value. Advantage has been taken of popular demand for certain marks, and they are freely manufactured both at home and abroad.

"The marks we give have been found upon old Worcester Porcelain, but many of them are only copies of Oriental devices. The painter, in copying the patterns from some Oriental piece, has completed his work by copying the device on the back also. But it is evident that such mark was not intended to deceive, as in many cases the Worcester Crescent is placed along with it.

Marks on Worcester Porcelain.—Figs. 394-5. Nos. 1, 2, 3, appear on all kinds of Worcester china from 1752 to about 1800. The crescent is the true Worcester mark; it was taken from one of the quarterings in the Warmstry arms.

Nos. 4 and 5.—The crescents, with addition, are not common; they are generally on blue ware.

Nos. 6, 7, 8, 9, 10.—The W mark is found on a great variety of patterns of early date.

Nos. 11, 12, 13, are the square marks so much sought after, and at present so freely forged.

Nos. 14, 15.—Also square marks, but not so common.

Nos. 16 to 22 are copies of Chinese and Japanese patterns, and generally appear on wares of that class.

Nos. 23 and 24, and 28 and 29, are imitations of the Dresden mark, but they appear on many styles of ware, sometimes even on black print.

Nos. 25, 26, 27, appear only on black transfer prints between 1756 and 1774.

No. 30 has been found impressed in the ware 1783 to 1791.

No. 31.—In blue under glaze for the same period.

No. 32 appears on the Royal service made for the Duke of Clarence.

No. 33.—This letter is found scratched in the clay after Mr. Barr was taken into partnership; from 1793 to about 1800.

No. 34.—From 1793 to 1807.

Nos. 35 and 37.—From 1807 to 1813.

Nos. 36 and 38.—From 1813 to 1840.

No. 39.—Used by Chamberlains, written with and without "Worcester," from 1788 to about 1804.

No. 40.—Written on specimens in 1814.

No. 41.—Printed mark used from 1814 to about 1820.

No. 42.—Printed mark used from 1820 to 1840.

No. 43.—Printed mark used between 1840 and 1845.

No. 44.—Printed mark used in 1847.

No. 45.—Used between 1847 and 1850; sometimes impressed in the ware, at other times printed upon it.

No. 46.—Mark used in 1850 and 1851.

No. 47.—Mark used by Kerr and Binns from 1852 to 1862.

No. 48.—Mark used by Kerr and Binns on special pieces.

No. 49.—Mark used by the present Company from 1862.

The figures in the concluding series are considered to be workmen's marks, and are generally, if not exclusively, found on blue painted wares.

It may be gratifying to our national pride to find that our porcelain productions have received the highest encomiums from our greatest rivals. M. Lameire, in his report on Modern Porcelains, shown at the Paris Exhibition of 1878, to the Minister of Instruction and the Fine Arts, remarks:—

"We must place here highest in rank the productions of the Worcester Manufactory. They are distinguished from all others by skill and accurate judgment in the Ceramic Art, and by great perfection in the execution.

"The bisque Parian, which reminds us rather of ivory than of marble, draws attention by its whitish-yellow tones, upon which foliage and fantastic animals in coloured gold (yellow and green) combine happily with the ground they decorate.

MOSAIC PICTURE, FORMING PORTION OF THE DINING-HALL FLOOR OF A HOUSE AT POMPEII.

SPECIMENS OF MOSAIC PAVEMENT.

SPECIMENS OF MOSAIC WORK.

"We must also notice services of simple outlines cleverly pierced.

"Let us equally notice large gourd-shaped vases with birds in gold, and foliage of a happy arrangement.

"Circular plaques also ornamented in the same manner, but upon grounds of red, black, or green, like Chinese lacquer, obtained by the great fire, show very remarkable results of powerful harmony, which we cannot however approve, when considered as imitations of another material in porcelain. Nor can we approve the long horns of Japanese form encircled by leaves and fruits completely detached, so closely imitating nature as to exclude all sentiment of decorative art.

"Having said this, we cannot speak too highly of the charm contained in each of these thousand objects, vases, table, dessert, and tea-services, where the ornament is always in harmony with the object decorated."

We have already briefly noticed, at page 525, *ante*, the ancient Mosaic-work, Tessellated Tiles, &c., of Roman manufacture. The most beautiful specimen of Roman pavement yet discovered in London was dug up in the year 1803, in Leadenhall-street, very near the ground formerly occupied by the East India House. It lay at the depth of only nine feet and a-half below the street; a sewer had cut away a considerable portion of it, but the central compartment, about eleven feet square, was nearly perfect. The whole is supposed to have formed the flooring of a room about twenty feet square. "In the centre was a figure of Bacchus reclining on the back of a tiger, holding his thyrsus erect in his left hand, while a small two-handled drinking-cup hung from his right; a wreath of vine-leaves circling his forehead, a purple and green mantle falling from his right shoulder and gathered round his waist, with a sandal on his extended left foot, the lacing of which reached to the calf of the leg. This design was surrounded by three circular borders, the first exhibiting on a party-coloured field, composed of dark grey, light grey, and red ribands, a serpent with a black back and white belly; the second, a series of white cornucopiæ indented in black; the third and innermost, a succession of concave squares. In two of the angular spaces between this last circle and the circumscribing rectangular border, were double-handled drinking-cups; in the other two, delineations of some unknown plant; both figures wrought in dark grey, red, and black, on a white ground. The square border surrounding the whole, consisted of two distinct belts, one described as bearing some resemblance to a bandeau of oak in dark and light grey, red, and white, on a black ground; the other exhibiting eight lozenge figures, with ends in the form of hatchets, in black on a white ground, enclosing circles of black, on each of which was the common ornament, a true-lover's knot. Beyond this was a margin at least five feet broad, formed of plainred tiles, each an inch square." The effect was remarkably striking.

Many other specimens of Roman pavement have been dug up in the various alterations which London has undergone within the last half century. Thus in the course of digging the foundation for an extension of the Bank of England, in 1805, a tessellated pavement was found at a depth of about eleven feet below the surface, and is now deposited in the British Museum; its dimensions are only four feet each way, and it occupied the centre of a floor about eleven feet square. In Cannon-street, in Holborn Hill, in Crutched Friars, in Broad-street, in Fenchurch-street, in Long Lane, in Eastcheap, in Lothbury, in Crosby-square, and in Threadneedle-street, specimens of these pavements have been brought to light: thereby showing that the use of such flooring was very common among the Romans. No longer ago than the year 1841, a specimen was found in the course of pulling down the French Protestant Church in Threadneedle-street, still glowing with wonderfully fresh and vivid colours. The Editor of this work had an opportunity of inspecting this pavement a few hours after it was laid bare, and he was astonished to see what was apparently a newly-painted picture, instead of mosaic-work, perhaps nearly twenty centuries old, that had been kept intact and uninjured, although covered with many tons of earth, rubbish, &c.

The manufacture of all varieties of inlaid floors or pavements, whether we call them mosaic or tessellated, depends on the arrangement of small coloured pieces in a definite pattern, the shapes being adapted to each other, and the whole brought to a uniform level. The mode of proceeding, however, differs considerably, according as a mosaic picture or a pavement of tessellated tiles be the object in view.

Where a picture rather than a pavement is required, enamel rather than stone is the material employed, as presenting greater facilities for adjustment in a delicate manner. There is first prepared a frame-work or foundation; then a layer of cement into which the mosaic may be imbedded; and lastly the mosaic pieces themselves. The framework, formed either of marble or of a volcanic stone called "piperino," is hollowed out to the depth of three or four inches, over the whole surface, except a portion to form a border at the edges. Grooves or channels, about one inch and a-half in depth, are cut in the excavated hollow of the marble, somewhat wider at the bottom than the top, as a means of retaining the cement afterwards applied. The subsequent mode of proceeding is described by Mr. Cadell, who witnessed it in Italy; and to his account we will have recourse.

The early mosaic-workers used, as a cement in which to imbed the mosaic pieces, a mixture of one part of slaked lime with three parts of pounded marble, made into a paste with water and white of egg. But this paste hardens too quickly, and solidifies before the workman can insert the pieces. It is, therefore, superseded by a mixture of one part of slaked lime with three of powdered travertine stone, mixed up with linseed oil, and stirred and worked every day with a trowel; the mass is at first level on

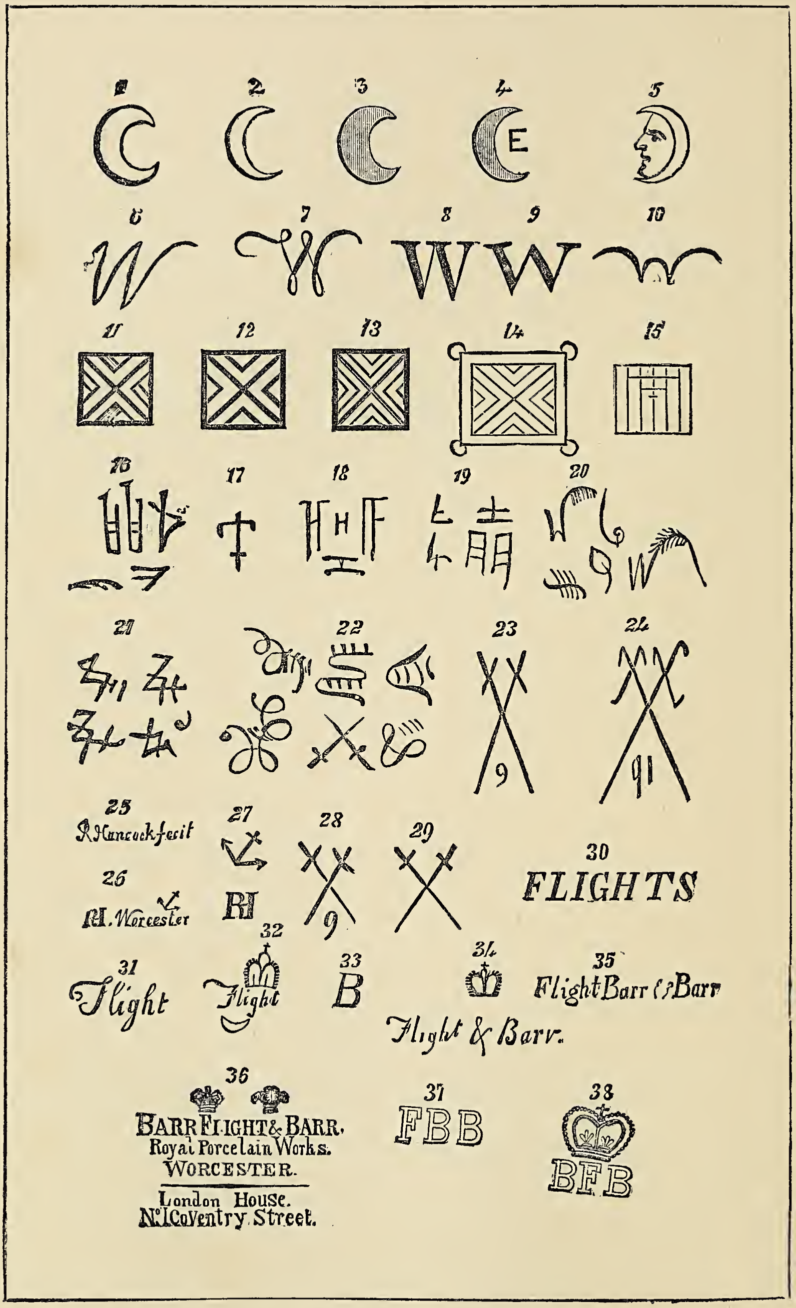


Fig. 394.—Marks on Worcester Porcelain.

Fig. 395.—Marks on Worcester Porcelain.

the surface, but afterwards swells up; each day more oil is added, to prevent it from becoming dry and intractable; and the mass is ready for use in a period varying from twenty to thirty days, according to the season of the year.

The next point is the preparation of the enamel pieces to form the mosaic. The materials, consisting of glass mixed with metallic colouring matter, are heated for eight days in a glass-house, each colour in a separate vessel. The melted enamel is taken out with an iron spoon, and poured on a polished marble slab placed horizontally, and another flat marble slab is laid upon the surface of the melted enamel, so that the enamel cools into the form of a round cake three-tenths of an inch thick. In order to divide these cakes into smaller pieces, each one is placed on a sharp steel anvil, called a "tagliuolo," which has the edge uppermost, and a stroke of an edged hammer is given on the upper surface of the cake: the enamel is thus divided into long square strips or prisms, which are cut to a length of nearly an inch. For small pictures the enamel, while in a melted state, is drawn into long quadrangular sticks, which are divided across by the anvil and hammer, or by a file. Sometimes these pieces are divided by a saw without teeth, used with emery, and they are, at others, polished on a lapidary's wheel. Gilt enamel is occasionally used: this is formed by applying gold-leaf to the hot surface of a brown enamel immediately after it is taken from the furnace, the two being made to adhere by a subsequent heating in the furnace. The colours of the pieces of enamel for producing a picture are extraordinarily numerous and varied. There is (or was some years ago) a manufactory of mosaic pictures belonging to the Pope at Rome, situated in a large building southward of St. Peter's. In this building the enamels, in the form of sticks about an inch in length, are arranged in a suite of rooms according to their tints; these tints are *seventeen thousand* in number, all arranged in labelled drawers, boxes, and cases, from which they are withdrawn to be used by the artist very much in the same way as a compositor uses type for printing, the colours in the one case being somewhat analogous to the letters in the other.

The framework, the cement, and the enamels being thus all prepared, the artist proceeds as follows:—The cement is laid on in small and convenient portions at a time, to the required thickness, and brought very smooth and level at the surface. The artist then, with the picture which he is to copy before him, selects one after another sticks of enamel of the proper colours, and imbeds them in the cement, taking them up and inserting them with forceps, and fixing them into the cement with a small flat wooden mallet, until their surfaces are level. If the effect does not please the artist, he takes them out and re-arranges them. The cement remains sufficiently soft for a fortnight or three weeks, so that the workman takes care to lay on no more cement at once than he can cover with enamel before it hardens. When one part of the picture is thus represented, more cement is laid on, and another part is done in a similar manner until all is enamelled. As there are likely to be minute crevices between the bits of enamel, they are filled up with powdered marble or enamel mixed with wax, which penetrates by having a heated iron passed over it. When the enamel has remained in its position two months, so as to allow the cement to harden, the upper surface is ground down and polished by means of a flat stone and emery—an exceedingly laborious process.

Such is the mode in which the delicate Italian pictures of mosaic enamel are produced, a mode necessarily involving a large expenditure of time and money. At the manufactory at Rome to which allusion has been made above, mosaic work is conducted on a large scale; the different materials are arranged in numerous apartments, from whence they are removed by the artists as occasion requires. Besides this establishment, there are many artists in Rome, occupied in smaller works, such as pictures of birds, insects, flowers, and other objects not exceeding two or three inches across; for such small specimens a framework or foundation of hardened copper is used instead of one of marble. As an example of the extraordinary minuteness of the work in some of these mosaics, we may state that there is one specimen, a portrait of Pope Paul V., in which the face alone consists of more than a million and a-half of fragments, each no larger than a millet seed! and from this size up to two inches square, pieces are employed in various ways. Another celebrated specimen was one which Napoleon ordered to be made when his power was paramount in Italy. It was to be a mosaic copy of the celebrated "Last Supper," by Leonardo da Vinci, and to be of the same size as the original, viz., twenty-four feet by twelve. The artist to whom the task was intrusted was Giacomo Raphael, and the men under his direction, eight or ten in number, were engaged for eight years on it. The mosaic cost more than seven thousand pounds, and afterwards came into the possession of the Emperor of Austria.

Some folio plates in this volume represent various kinds of mosaic work, all being executed apparently either by the Romans, or while the Romans were in power. It is frequently the practice to denominate as "mosaic pictures" those which represent scenes or events, and as "tessellated pavements" those which exhibit simpler designs.

THE MANUFACTURE OF GLASS.

In the Introduction to this work, the reader will find, at pp. lxiii. to lxv., a detailed account of the early history of the glass manufacture. We shall now proceed to describe the practical details of the subject.

Nature and Constituents of Glass.—Generally speaking, the various kinds of glass usually manufactured may be divided into *Flint*, or that which is used for making jugs, wine and other glasses, with various domestic vessels; *Crown* or *Window*, such as is employed in glazing sashes; *Plate*, used for windows, mirrors, &c.; and *Bottle*, which is the coarsest of all kinds, but one of great extent, including, as it does, the

wine and beer-bottle trade. To these may be added various modifications of window-glass, in the form of slabs, tiles, &c.

The term *flint-glass* is derived from the fact that, at one time, the silicious portion was derived from powdered flints; but, in making all kinds of glass, sand is universally employed at the present day, such a selection of the article being made as circumstances require.

Theoretically, pure glass would simply consist of silica and alkali fused together; but such is never manufactured for commercial purposes, because it would be deficient in a variety of qualities that are desirable. It is a remarkable fact, that all our precious stones, with the exception of the diamond, are similar in composition to glass, with this exception, however, that some of them contain alumina, which ordinary glass does not. Again, whilst glass is produced by fusion of its ingredients at a high temperature, there is no doubt that gems have all been produced by the slow crystallisation of their constituents from solution in water. The term *crystal* is commonly applied to flint-glass, on account of its brilliancy when properly made.

Turning attention first to flint-glass, we may notice separately the ingredients that are employed in making it.

Silica has already been described in connection with pottery. The purest form in which it occurs in nature, is that of quartz, or rock-crystal. In flint it is found in a solid black mass, as already explained at p. 530, *ante*. The sand of the sea-shore, and that of some heaths, is composed of nearly pure silica. The flint-glass-makers get their supply from Alum Bay, in the Isle of Wight; the Lynn river, Aylesbury, and other places; but that got from the forest of Fontainebleau is the most suitable for flint-glass-making.

Several qualities are requisite in the sand. Its texture or grain should be even, and neither too large nor small, as if it be the first, it requires a large expenditure of alkali and fuel to bring it into fusion; and if too small it is apt to form specks. It is carefully washed before use, so as to remove all extraneous matter as far as possible.

Alkalies.—Potash and soda, when fused with silica, form glass. If the alkali be greatly in excess, a glass soluble in water is produced, as described at p. 529, *ante*, and that has been used to coat stone in process of decay from exposure to the weather. The best glass, as the Bohemian, &c., is made with potash, and it is exceedingly hard, melting at a much higher temperature than glass made with soda. For many chemical vessels this hard glass is very valuable, as it is not liable to suddenly melt down.

In reference to the use of alkalies, and their choice, the following remarks of Mr. Pellatt, the celebrated flint-glass-maker in London, quoted from a work he has kindly placed in our hands, are exceedingly judicious and scientific. "Tempted by the difference in the cost, many manufacturers are using soda in the composition of their glass; and although, at first sight, no difference in quality can be detected, yet, eventually, it will be found that the glass is rendered useless thereby. From the minute, but perceptible exudation of the soda, appearing like vapour upon the surface, such glass requires almost constant cleaning; in use, more especially with water containing carbonate of lime [chalk in solution], such glass is soon covered with an opaque coating, which cannot be removed: this arises from the water having a greater affinity for the soda in the glass, than for the lime which it holds in solution. The soda is therefore taken up by the water, and the lime is deposited on the glass. From this cause, glass has been known to have become unserviceable after a very few years; and it is to be feared that a large portion of the flint-glass now being made will likewise so fail."

On this point we may remind our electrical friends of a fact that must have been frequently observed. It is the difficulty with which some glass is excited by friction, and that some Leyden jars, with equal difficulty, retain a charge even in comparatively dry weather. Some years ago, having purchased a three-feet plate machine, after a short use the glass fractured at the centre. Having ordered another plate of the best glass, this was fixed in the same frame as that previously used; and all the arrangements of rubbers, insulators, &c., remained as before. But we could never get two-thirds of the amount of electricity from this second plate; and, in wet weather, a spark could scarcely be got. After much trial of patience, especially in public experiments in a room filled with moisture from the breath of the audience, we determined on having a fresh plate, which answered perfectly well. After careful examination, we found that the defective plate gradually became covered with a deposit exactly like perspiration, which, of course, would absolutely destroy every chance of exciting it, and keeping it insulated. This, doubtless, arose from the causes alluded to in the remarks just quoted from Mr. Pellatt, and which are, consequently, highly deserving of the attention of all engaged in practical electrical investigations.

In using the carbonate of potash, it is mixed with about half its weight of nitrate of potash, or nitre, the latter affording oxygen; and, consequently, highly valuable, for reasons that will subsequently appear.

But, besides silica and alkali, other substances, having great influence on the density and colour of glass, are employed. They are as follow:—

Lead.—This metal is used in the state of oxide, either the protoxide or peroxide, preference being given to the latter. It increases the fusibility and ductility of the glass produced only by silica and an alkali, and also adds density and brilliancy to the manufactured article. Mr. Pellatt expresses the opinion that the superior quality of British flint-glass, is greatly due to the very careful manner in which the oxides of lead are prepared for the glass-maker's use.

Manganese.—The oxide of this metal is of the

highest value to the glass-maker; for by it he can correct a tendency to a green colour that glass made with the previously named ingredients is liable to.

Its office is to afford oxygen, so as to correct the deoxidating influence that acts on the impurities of glass at a high temperature. Thus, if a piece of common glass tube be heated red-hot in the flame of a lamp or candle, it will gradually turn to a purple or black, owing to the reduction, or loss of oxygen, in the oxide of lead partly composing the glass. But great care is required in using this material; for, if added in the slightest excess, it affords a purple colour: a quarter of an ounce produces a sensible alteration of colour in 16 cwt. of glass. The eminent authority already quoted, remarks—"The green tint may be made to give place to the purple when glass is slowly heated to redness in contact with the atmosphere, as in the process of drop-pinching: this change is, in all probability, due to the oxygen it takes up from the air. Nor is it necessary that heat be employed to effect this. Exposure to the atmosphere for a long period equally effects a change of colour. Indeed, the colour of all glass is changed sooner or later, according to the base of the colouring matter. Flint-glass, perhaps, from the quantity of lead entering into its composition, is less affected than other glasses; but plate and window-glass are very susceptible. Colourless glass of this description, in which there is manganese, becomes purple. Light-green tinted glass, in which the colouring base is copper or iron, is changed to a straw colour, yellow, and, ultimately, red. The whole art of producing colourless flint-glass lies in the proper regulation of the quantity of oxide of manganese, which must be augmented with the increased degree of heat to which the materials are subjected. This, however, is a matter of some difficulty, because every change of external temperature affects the general heat of the furnace; and many other substances affect the degrees of heat applied to particular crucibles in the furnace; so that nothing but a course of practical experience, the results of minute observation, can cope with these varying circumstances."

The preceding are the materials employed by the flint-glass-maker. The proportions in which the first three are used, vary with different manufacturers; but one part, by weight, of alkali, two of lead, and three of sand, are considered to approach nearest to the proper proportion for making the best flint-glass. The materials are mixed as completely as possible before being introduced into the crucible; so that, when melted, every part of the "metal," as the liquid mass is termed, may be homogeneous; and on this will essentially depend the quality of glass that results from the fusion; for, if the mixture be not even, it will contain spots and wavy lines, that may easily be seen in badly-made articles of flint and other glass, and which completely spoil their beauty, and injure their transparency.

The mixture is then introduced into crucibles, represented, with their mouth, in the following cut. These are made of the most refractory

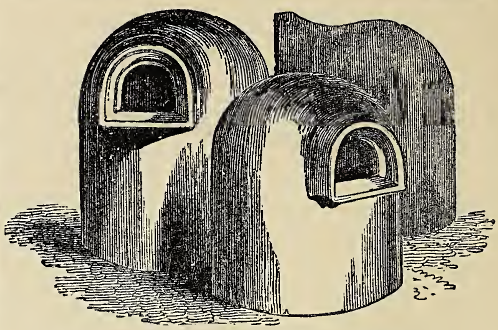


Fig. 396.—Crucibles for Glass-making.

Stourbridge clay, a material largely employed in all the arts where intense heat is required; as for lining iron furnaces, for chemical furnaces, &c., &c. Those intended for the glass-maker's use are manufactured with the greatest possible care, so as to be free from air-bubbles or other chances of injury when they are exposed to intense heat.

The glass furnace is built in a circular form, in such a manner that the heat plays round the crucibles, so as to keep them, as far as possible, at the same temperature on all sides. In the following cut the arrangement of crucibles, flue,

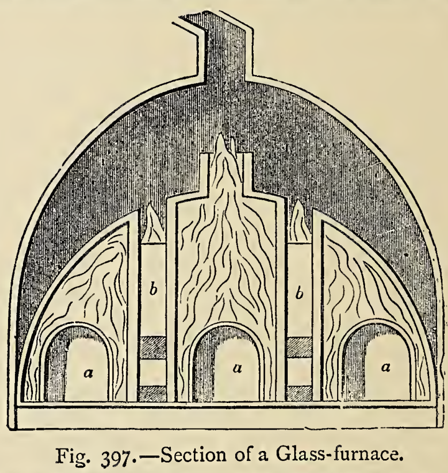


Fig. 397.—Section of a Glass-furnace.

&c., is represented. *a* shows sections of the crucibles just described, and containing the metal. It will be seen that the flame plays round them by *b b*, which are the flues. The smoke and hot air from the latter escape through a chimney in the centre of the furnace. The internal arrangements of its base are illustrated by the following engraving. It gives a horizontal and sectional view. *a* are the flues for heating the furnace; *b*, the ground or base on which the crucibles or melting-pots rest; *c*, these crucibles; and *d*, a central grate for admitting air to the furnace, the air passing by an underground tunnel to this grate, to support combustion of the fuel. It will be seen, therefore,

that whilst the mouth of each crucible is open to the glass-house, every other part of the

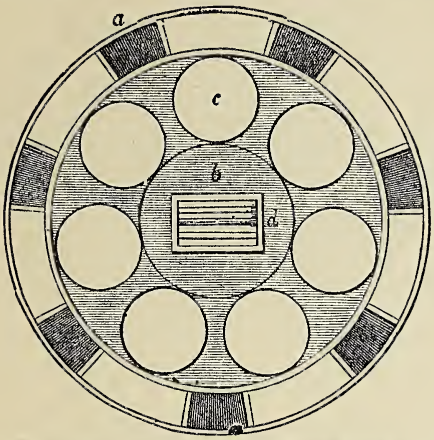


Fig. 398.—Ground-plan of a Glass-furnace.

crucible is closed, so that neither flame nor smoke can enter. As we shall subsequently explain, the workman takes the metal out of these mouths, which present a glowing melted mass nearly a yard deep and wide, and affording a curious and beautiful appearance to a stranger.

Of course the consumption of fuel is vast in the glass-house, and consequently, in every way, its economy is studied. The internal arrangement is, therefore, such, that whilst all unnecessary air is excluded, except what is absolutely necessary, still sufficient draught is secured to reverberate the flame on the crucibles, and keep all parts of them at as high a temperature as can be maintained, and, at the same time, one as even as possible.

At times, old glass, of a similar quality to that intended to be produced, is mixed up with the "batch," as the material in the crucible is termed; but the best glass is made entirely from fresh materials. The melting in the furnace takes about sixty hours, during which the metal assumes several successive appearances. "After the first ten or twelve hours it appears as a honey-combed mass, very white, and perfectly opaque; in a few more hours the opaque appearance yields to a transparent body, filled with thousands of air-bubbles; the white colour now gives place to a light purple tint, produced by the oxygen given off from the oxide of manganese. As the melting continues, the purple tint gradually vanishes, the air-bubbles become fewer and larger, and, at length, quite disappear, when the glass is fined, and ready for manipulation. This is an interesting process, differing from every other, inasmuch as a change in the organisation of the material takes place, and that so instantaneously as to appear the effect of magic. That which, a moment before, appeared an opaque, semi-fluid, and non-lucent body, without form, and apparently of a bright yellow colour, in a moment assumes various opposite qualities.

"The opaque is now beautifully transparent; the semi-fluid, a colourless solid of the most perfect molecular structure; and whilst these changes take place, the utmost symmetry of form has been acquired,

"The *manipulation* depends upon certain general properties which glass possesses. At a red heat one piece of glass is welded to another by mere contact; at a lower temperature, in contact with cold iron, glass is fractured evenly and horizontally, and may also be cut with scissors with nearly the same ease as cloth; and, at a higher temperature, may be elongated to any extent—in this respect being superior to the most ductile metal. It may be spun to the finest hair, or blown to an almost imperceptible substance."

The preceding quotation, or rather its last paragraph, gives a general view of the different processes that are employed with the fused metal, as taken out of the pot to convert it into a number of useful articles; and each of these processes we can now examine in detail.

The mechanical contrivances are of the simplest character, and consist of the *blowing-iron*, the *punty*, the *procellos*, the *shears* or *scissors*, the *battledore*, and the *pincers*. The blowing-iron is simply a long hollow tube of iron, about six or seven feet long. It is inserted into the melted "metal," a portion of this being drawn out of the crucible at the end of the iron. The latter is whirled over the workman's head to lengthen the mass of glass at the end, and then it is rolled on a flat plate or lathe, to reduce it to a cylindrical shape, as represented in the following cut. The metal, still as pliant as clay,

Fig. 399.—Glass-blowing.

is then blown into through the iron, as shown in Fig. 400. It thus becomes hollow; and to keep its cylindrical form, or to modify it, the newly-formed hollow vessel is rolled as before. But after two or three such operations the glass loses its pliancy, and it is accordingly inserted into the mouth of the crucible, as shown in Fig. 401, Blowing is had recourse to again, so as to produce the pear-shape of a vessel—say a decanter. The *procellos*, which resemble a pair of sugar-tongs, are now called into use, and by this means the shaping of the vessel is more completely effected, whilst the rim or neck is

also formed, as illustrated in Fig. 402, By continuing these various processes, any desired shape

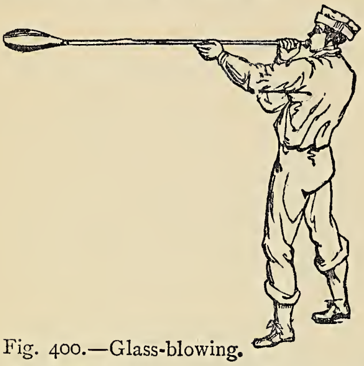


Fig. 400.—Glass-blowing.

of circular vessel may be produced, which is done almost by magic, and in less time than is required to pen this description. According to the form of the vessel, or its uses, various parts are

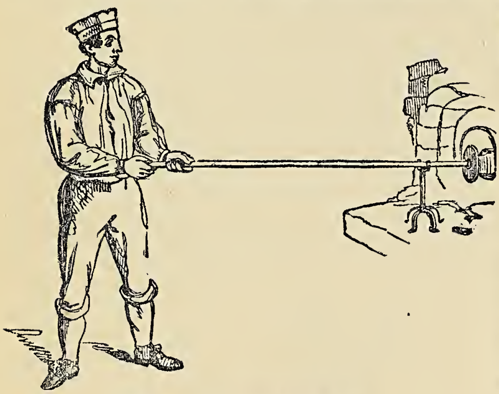


Fig. 401.—Glass-blowing.

made whilst the glass is pliant. A lip is made by cutting away a portion of the neck, being, after, completely formed by another tool. The pliancy of the glass permits of its assuming any form, and thus handles or feet are added with the greatest ease, by other pieces of melted glass, and shaping them to the requisite form. Whilst still red-hot they are applied to the requisite portion of the vessel, which is thus gradually brought to an almost complete state. When the vessel is thus finished, it is readily detached from the blowing-iron by touching it at the bottom with a cold iron.

Various modifications of these methods are adopted in making different forms of vessels; but still all are conducted on the principles already described—that is, on the complete pliancy of the glass at a red heat, and the consequent facility with which it can be bent, moulded, blown, or rolled into any required form; but some of these methods adopted to fashion special-shaped masses of glass, will be more fully noticed presently, our attention, for the moment, being confined to the manufacture of flint-glass vessels, such as tumblers, decanters, jugs, and the like.

The vessels thus formed, however, apparently perfect as regards shape, have yet a quality that

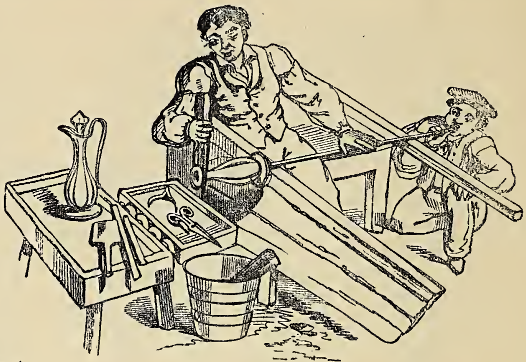


Fig. 402.—Shaping a Flint-glass Vessel.

renders them all but useless if employed in domestic life. The particles of the glass, as it cools, tend to separate from each other, but are held together by the powerful force of cohesion, or cohesive attraction. Thus, if such a vessel experienced a sudden change of temperature, it would instantly fly to pieces, as is familiarly known to occur in glass vessels purchased at a cheap rate at the shops. This result is interestingly shown in the toy called Rupert's drops. These are pieces of glass of a pear-like shape, produced by dropping a little melted glass into cold water. These masses may be struck with a hammer, when cold, without being broken; but if they are scratched with a piece of sand, they will instantly fly to pieces or in powder. For the same reason, the unannealed tumbler or jug is destroyed by pouring hot water into it. A curious optical effect is also shown by such glass; for, whilst a piece of well-annealed plate-glass presents no change under the polariscope, one unannealed affords the most beautiful play of colours. The annexed cut represents a square piece of glass presenting such an appearance. The dots are supposed to be of a rich blue colour, separated by a white cross; which, if the analyser be turned round 90°, will change into a black cross, whilst the dots turn to an orange red.

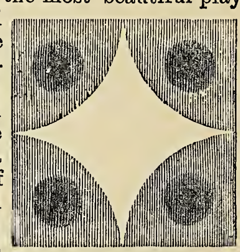


Fig. 403.—Unannealed Glass.

The process of *annealing* must, therefore, be had recourse to. It is remarkably simple, and consists of raising the temperature of the vessels to a height less than sufficient to melt them, and afterwards to allow them to cool very gradually. The articles are placed in an iron pan, called a liering-pan, and transferred to a low vaulted arch, having a strong fire at both sides, at the end nearest the glass-house. By means of a chimney a draught is created, by which the flame is drawn some distance down the arch, or oven, that is called the "lier." The length of

time that the articles require for gradually cooling, will depend on their thickness; for, of course, the thicker the vessel, the longer will it take to effect the process. From one to three days, are, on the average, required to perfect the annealing of such articles of flint-glass as are in common use. Mr. Pellatt observes—"Annealing affects the colour of glass; the amount of change depending upon the nature of the fuel, and the period of time during which the glass is exposed to it. Glass of a purple tint, during annealing, becomes colourless; if the process be too long continued, it changes to green; and glass apparently colourless previously to annealing, is afterwards tinged with green. The more carbonaceous the fuel used, the sooner are these results obtained. Glass previously to annealing is more brilliant than after; and as the process reduces its brilliancy, the glass-maker should be careful of the degree to which he carries the process."

Such are the leading features of the manufacture of flint-glass; and we have merely traced the process in connection with the manufacture of such articles as are used in domestic affairs. But it must be remembered that its uses are far more extended. For optical instruments it is largely employed, and in this its high refractive power is of great value. In making telescopes, the lenses require this peculiar property to the highest degree possible; and the same holds good in reference to microscopes. But an evil creeps in from the dispersive power of such glass; that is, many of the rays are lost: and as such glass produces two different foci, according to the refrangibility of the different rays of the spectrum, the result is the production of a coloured fringe, which greatly tends to confuse the image of the object in either the telescope or microscope. This evil, however, is done away with by means of an admirable but very simple contrivance. The dispersive power of the flint-glass is corrected thus:—A double concave lens of flint-glass is fitted to a double convex one of crown-glass, hereafter to be described; and thus, either for microscope or telescope, what is called an achromatic lens is produced; that is, one which affords no coloured fringe, and which, consequently, prevents a large loss of light that would otherwise occur. Such an arrangement is shown in the margin; *a* representing the concave flint lens, and *b* the convex one of crown-glass.

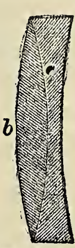


Fig. 404.

To the philosopher, consequently, a good lens of flint-glass is a source of the deepest interest in the study of light. It is familiarly known that a triangular form of glass, called a prism, has the power of decomposing light, and resolving it into its elementary colours. This fact was recognised in Sir Isaac Newton's days; and, indeed, was the basis of his important discoveries in reference to the laws of light. But the chemistry of glass-making was then but little known; and, consequently, the power of research was limited in the employment of that article in experiments in optics. Still later, and, indeed, in this century, Fraunhöfer, possessing an excellent lens of flint-glass, discovered that, beside the coloured portion of the spectrum, an immense number of black lines are formed when light is passed through such a prism. Such lines result from what is called the "interference of light," which may be briefly described as the effect or result of sets of opposed waves neutralising each other, and producing darkness. A step further, by the use of an excellent flint-glass prism, led Bunsen and Kirchoff to the discovery of spectrum analysis, by aid of which we can detect solid matter in combustion, as in flame, when the quantity is so minute as to be less than the fraction of a millionth part of a grain. Faraday made many experiments in producing a highly refractive or heavy glass; and although, commercially, the results he obtained were of no great practical value, still they became of the highest importance in the interest of science, and enlarged our views in respect to the connection of each force in nature, but especially of light, electricity, and magnetism, that laid the foundation of some of his most important discoveries, and will ever perpetuate his name.

It is thus seen that, as art advances, science benefits; whilst, as already shown in our previous pages, a careful and judicious application of science is of equal benefit to art. They go hand-in-hand in their progress for the benefit of mankind.

The different instruments just briefly alluded to, and the consideration of such articles as are of domestic use, lead us to another branch of the glass manufacture, known as cutting, grinding, and engraving.

By the term cutting, we do not simply mean the division of a piece of glass by the use of the glazier's diamond, such as is figured in the margin. The two small figures on the right hand of the cut, represent the mode of setting the diamond, which is a small portion of the gem fixed at a certain angle. Even the ordinary steel file may be used for cutting glass, simply so far as dividing it regularly into two or more pieces is concerned.

By glass-cutting we mean that process by which the sides of a circular or other flint-glass vessel or body are made on the surface. As Mr. Pellatt observes (and the process is represented in the following engraving)—"Glass-cutting is the art of forming figures and patterns upon the plain surface of glass articles, by grinding away the glass with iron wheels and sand; soft stone and wood wheels follow, in order to smooth and polish the figures formed by the iron wheels. The object to be obtained in cutting glass, is to present such a surface to the rays of light, that instead of their passing directly through the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glass, they may be broken or refracted, so that a 'play of light,' as it may be termed, is always on the surface. To effect this, it is neces-

Fig. 406.—Glass-cutting.

sary that the lines forming the figure or pattern upon the exterior of the glass, be the reverse of the line of the interior ; and that the indentations upon the surface, or the projections left by them, be such as to form angles, hollows, or projections. In the cutting called diamond or prism-cutting, this object is at once obtained : the same effect is also produced by fluting, or flat-cutting ; because, wherever two flat cuts meet, an angle is produced, forming, with the line of the interior, an imperfect prism. The broader the flat cuts the more acute the angle, and, consequently, the greater the refraction of light ; and as these flat cuts are made upon a circular surface, the broader the flats are, the more expensive they become. The same theory holds good in all lapidary or flat-cutting on solid glass ; that is, where the cutting is all over the surface. To produce the requisite effect, it is essential that, whatever the patterns, flats must be opposite angles : it is by this that the refraction, so necessary to the play of light upon chandelier work, is obtained." The excellent imitation of the Koh-i-noor diamond in flint-glass, also illustrates these principles.

The practical part of this cutting is very simple, as already illustrated by the preceding engraving. The workman has a wheel before him, revolving on its axis in a vertical direction ; and it is kept coated by a thin covering of fine sand and water. The glass vessel to be cut is pressed at its edges against the wheel, and gradually its sides become abraded, or worn down, so as to expose a flat surface. By varying the position of the glass he can make flat cuts in any desired direction. As soon as all the desired pattern is thus cut, the cut surface is smoothed down against stone wheels ; and, at last, the surface is polished by being pressed against wooden wheels coated with putty-powder, or tripoli. By such means all cut surfaces on flint-glass are produced, and an ornamental character given to it.

Glass-engraving is carried out in a somewhat similar manner ; but very small wheels are used, moistened with oil and emery-powder. The following cut represents the method adopted, which

Fig. 407.—Glass-engraving.

does not essentially differ from "cutting," except in the fact that the roughened surface is not polished, but left to present, by its dead surface, one contrasting with the other polished exterior of the glass.

Both these processes are quickly carried on by experienced hands ; and if such possess a refined taste, beautiful effects of an artistic nature are produced. In this respect, as in every branch of ornamentation, great improvement and advance have been recently made ; but still there is abundance of room left for further improvement, and a higher display of elegance in design. Just as in pottery, the art of ornamenting glass is comparatively in its infancy ; and modern art has yet to beat that which, in ancient times, produced the Barberini or Portland Vase. Of late years, however,

public taste—that is, such as is shown by purchasers—has stimulated a wholesome excitement, which has resulted in the production of some beautiful objects in cut and engraved glass. In the Exhibition reports of 1862, it is observed that "the jurors have great pleasure in stating, from their knowledge of the goods produced for several years past in their various localities, and from their recollection of the goods exhibited in 1851, that laudable progress has been made in all branches" of the glass manufacture. The peculiar advantages which it is considered the British have over foreign producers of flint-glass, they attribute to the superior quality of the fuel and materials of this country. "The first enables the manufacturer to use a greater proportion of silica in his glass, thereby producing a closer and stronger texture of body, preventing what is technically known as 'sweating' in plate-glass (see *ante*, p. 547); and, by the second, the greater purity and brilliancy of flint-glass is obtained. Another advantage secured by this country, possessing fuel of the greatest power, is, that in superior qualities of glass, the manufacturer is enabled to fuse his materials in covered and larger crucibles, entirely protected from the action of the fuel: and this is a great advantage, inasmuch as the colour of the glass is very much deteriorated by the carbon of the fuel passing over the fluxed materials, the carbon absorbing oxygen, and rendering the glass of a green tint (see *ante*, p. 548). The same cause, the presence of carbon, prevents the use, in uncovered crucibles, of the oxide of lead (see *ante*, p. 547), except to a small extent, the deoxidation of the metal resulting in the formation of metallic lead, which, by its own density, falls to the bottom of the crucible."

We next turn attention to another branch of the glass manufacture—namely, that of

Colouring Glass.—One of the most beautiful objects that can be produced by art is that of a richly-stained glass window; and next to that, the varieties of flint-glass articles having one or more colours. The art of staining may be said to be in revival in this country, especially as popular taste, amongst those who have sufficient means of gratifying it, is leading in that direction. One of the latest and largest additions to cathedral decorations of this kind is that of the cathedral of Glasgow, in which some of the wealthiest inhabitants of that flourishing city have erected "painted" windows, at a cost varying from £1,000 to £3,000 each.

But we must first guard our readers from misuse of the word painted. If plain white glass was coloured only on the exterior by a coating of colour, by simple painting, a few weeks' exposure to the atmosphere would remove that coat, and, of course, the colour. Painted windows, so called, are composed of pieces of glass, in which the colour is burnt in, and, consequently, is all but indestructible by time; hence many of our old cathedral windows present just as fresh and rich an appearance as they did years or centuries ago.

The operations of staining glass for windows, and of colouring flint-glass for vases, &c., &c., being identical in character, we shall include notice of both under this heading.

Formerly—even a thousand years back—stained glass was used in ornamenting churches and other buildings. The method then adopted was that of forming a kind of mosaic work, by connecting small pieces of glass, edge to edge, until the design was thus built up. The work so executed was of a very excellent kind. Winckelman thus describes an ancient one, representing a duck:—"The outlines are well defined and sharp, the colours beautiful and pure, and have a very striking and beautiful effect, because the artist, according to the nature of the parts, has in some employed an opaque, and in others a transparent glass. The most delicate pencil of the miniature painter could not have traced more accurately and distinctly either the circle of the pupil of the eye, or the apparently scaly feathers on the breast and wings. But the admiration of the beholder is at the highest pitch when, by reversing the glass, he sees the same bird in reverse, without perceiving any difference in the smallest points; whence we could not but conclude that this picture is continued through the whole thickness of the specimen, and that if the glass were cut transversely, the same picture of the duck would be found represented in the several slabs—a conclusion which was still further confirmed by the transparent places of some beautiful colours upon the eye and breast that were observed. The painting has, on both sides, a granular appearance, and seems to have been formed in the manner of mosaic work, of single pieces, but so accurately united, that a powerful magnifying-glass was unable to discover any junctures." It has been suggested that this singular and beautiful piece of glass-work was made thus:—"Slender glass rods, or pins, being selected, and arranged in the proper order of colours, they were laid side by side, in the manner of types, and were then gently fused at the surface to cause them to amalgamate. Supposing, however, that this was really the mode, a rare amount of delicacy and skill must have been required to melt away, as it were, the lines of junction, without allowing one colour to run into another."

At first, the glass used for ecclesiastical decoration was really painted; but, at a more recent period, the art of burning-in the colours, and of thus rendering them permanent, became known, and has ever since been adopted for such purposes.

Staining, or colouring glass, as now pursued, consists in adding to ordinary glass mixtures oxides or carbonates of some of the metals for colouring flint-glass, and of firing these together, when a coloured glass will be produced; whilst, for staining flat or window-glass, the same oxides are painted or laid on to ordinary flat glass, and this is then heated until a fusion of its surface admits of the incorporation of the colouring matter. "It is usual to ascribe one particular colour to a particular metal—say, blue to cobalt, and green to copper; but Bontemps has shown that *all* the colours of the

spectrum may be produced by any one of the ordinary metals, which he ascribed to the degree of heat to which the mixture or the colouring metal is subjected.

"In all instances of change of colour of glass, heat can only be the *agent* by which the change is effected, the colour depending upon the combination of the metallic base with oxygen or carbon, and upon the particular molecular structure of the glass resulting therefrom.

"This may be proved by plunging into a crucible of light-green glass, the colouring of which is [the protoxide of] iron, a pole of green wood: so long as it is retained in the glass, volumes of gas are given off; and, upon its being withdrawn, it is found that the colour has become yellow, the same colour as would have resulted from the use, in the first instance, of carburet [carbide] of iron. At every repetition of the poling the yellow colour becomes deeper, and, eventually, the glass becomes jet black.

"To this black glass add a few pounds of oxide of manganese, stirring the glass well; when, after subsiding for a few hours, the black colour entirely disappears, and the original green colour returns; the colour being the same as previous to the deoxidation of the glass. Other colouring bases are similarly affected. Thus the beautifully stained ruby glass for which the Bohemians are so famed, is produced by a preparation of the protoxide of copper; this is painted over white glass articles, which are bedded in charcoal, and brought to a red heat in a kiln. In the absence of charcoal, the colour produced by the copper would be green; but the charcoal deoxidises the copper, leaving the colour of the metallic copper dark ruby. To produce this beautiful tint in perfection, the white glass must be made without lead, because the carbon partially reduces the lead in the glass as well as the copper upon it, leaving, in place of a bright ruby, a dull opaque colour, known to glass-makers by the expressive term of 'livery' or 'liver-colour.' The ancient ruby glass was not a surface, but a body colour; and, by analysis, the colouring base was found to be copper: but how the melted glass could be manipulated without taking up oxygen from the atmosphere, is unknown; it is probable that the great beauty of the ancient glass is, in some measure, due to its age."

In confirmation of a portion of the preceding remarks of Mr. Pellatt, we may relate the following:—In 1857, at the destruction of the Glasgow Polytechnic Institution by fire, a beautiful piece of light cut pink glass, or, perhaps, of a light ruby colour, was amongst the specimens in the collection deposited by Baillie Couper, of St. Rollox Glass-works. On being discovered, after the ruins were cooled, it was found completely black, not allowing the least transmission of light even on its thinnest edge.

Mr. Pellatt gives the following remarks on the colouring matter used in giving colour to flint and other glass:—

"The rose colour, produced by the oxide of gold, is dependent upon the combination of the base with oxygen and carbon; assuming almost every colour from white to black, according to the presence of these agents: iron, copper, cobalt, manganese, gold, and uranium are the metals used in colouring glass; and these bases, in combination with various proportions of oxygen, produce all the coloured glass in general use.

"The ordinary shades of green are the product of the oxides of iron and copper in different proportions; the yellow tints being due to the iron, and the blue tints to the copper. The carburet [or carbide] of iron gives a dull yellow colour; blue is produced by the oxide of cobalt; purple, by the oxide of manganese; and the varieties of rose and ruby, by the oxide of gold: topaz is given by the oxide of uranium; and emerald green by the same metal, with the addition of a small quantity of copper. Glass is rendered opaque by the addition of arsenic; and the peculiar colour of the opal is produced by phosphate of lime. The quality of all colour in glass, is the result of a proper degree of heat during the fusion of the materials; or, in other words, the prevention, as much as possible, of deoxidation during the process. A variety of colours upon the same article is produced by thin coatings of each being united in the manipulation; so that, in the after process of cutting, one colour or more is made to appear as may be desired, according to the depth of the cutting; the difficulty, in this process, is the proper union of the several glasses; as, should any difference exist in what is known to glass-makers as the 'temper of the metal,' the contraction, or atomic arrangement during the annealing, will vary sufficiently to cause fracture."

To the preceding outline of what is the science of glass-colouring, we may add a few words more in respect to the practical part. It will be evident that a glass vessel of *one* colour, is produced by blowing glass of that colour. But the process described in the conclusion of the last paragraph, will not, perhaps, be fully understood, by many of our readers, without some further explanation. The method is that by which the beautiful Bohemian vases of many colours, used for mantelpiece ornaments, are produced. It may be popularly explained as follows:—We will suppose that it is desired to form a vase having three colours. The first may be red; and this coloured glass is blown, rolled, and otherwise fashioned into the form of the vessel (except such modifications as may be produced by cutting), in the manner described at pp. 549, 550, *ante*. This being done, the vessel is dipped into a glass of another colour, say yellow; and, on this cooling, it is dipped into the third colour, say blue. Accordingly, the *inside* of the vessel is of a red colour, its *exterior* of a blue, and *between* these is a layer of yellow. Now it is evident, that if the exterior or blue be ground away, the yellow sub-colour will appear; again, if this be ground away, the interior red will appear; and so, by varying the depth of the cutting, any of the three colours, or all of them, may be brought to the surface on different parts of the vessel.

The method of producing stained glass for windows is different. It is lucidly explained as follows :—A painted window is usually built up of two kinds of materials ; the one being a piece of stained glass, and the other pieces of painted glass. In a draped figure, for instance, the features and all the minute details, in which frequent change of colour or tint takes place, are painted ; whilst, in broad masses of drapery, where there may be a tolerably large surface of one tint, a piece of glass that has been stained of that tint in the making is used, cut to the requisite size and shape. Or the two methods may be used conjointly, by partially painting a piece of glass which had previously been stained of one uniform colour. When a sufficient number of pieces of the different kinds are prepared, they are placed together, edge to edge, and formed into a picture, the joints being secured by glazier's lead ; and being so chosen in position as to occur at the shaded parts of the picture. In producing the stained glass, the metallic colouring ingredients are thrown into the melting-pot with sand, alkali, &c. ; and sheets of coloured glass are formed from the mixture, in the same way as colourless glass under ordinary circumstances. To produce the painted glass, the device is properly drawn and coloured on paper, and is fixed down to one surface of the properly-shaped piece of glass. It appears then like a drawing seen through the glass ; and the artist paints, on the outer surface of the glass, an exact copy of this picture—following all the lines of the device, and adapting his colours accordingly. These colours are formed of the metals or metallic oxides just alluded to, ground up with flint-glass, oxide of lead, and borax, and moistened with one or more of several liquids—including turpentine, amber oil, capivi balsam, and gum-water. The metallic agents give colour ; the flint-glass, lead, and borax enable the whole to be fused or vitrified ; and the liquids enable the painter to apply the colours.

When the device, or picture, is thus painted, the piece of glass is exposed to a degree of heat sufficient to fuse the paint, and convert it into a kind of glass, which combines with the substance of the glass on which it is laid. The piece of painted glass is placed in an iron box called a "muffle," in which it is rested on iron shelves covered with powdered lime, to prevent adhesion. The muffle is then placed in a furnace, heated with coke or charcoal, and exposed to a heat which requires to be managed with a high degree of care and skill ; the glassy paint (for we may so term the material with which the device is painted) is just heated sufficiently to be vitrified, and to combine with the glass beneath—a temperature either a little above or below a particular point being likely to spoil the whole operation. There are hollow tubes, so inserted that the operator can look through them, and see how the process advances. When brought to a conclusion, the fire is allowed to die away gradually, and the piece of glass is removed from the muffle. Part only of the colouring ingredients have been absorbed into the substance of the glass ; the rest is scraped off, and preserved, to be used again ; for many of the colours or pigments employed are very valuable. If, when examined, the glass exhibits defective places, or wrong tints, it is partially touched over, and again exposed to the heat of the oven. A great part of the stainer's art consists in this—that the colours, as they appear on the pallet, do not accord with those afterwards seen through the painted and stained glass when burnt in, so that there is a kind of guess-work as to the result of his labours, such as is not encountered by the artist who paints with oil-colours on canvas.

Crown or Window-glass.—This branch of the art of glass-making differs, in several respects, from that adopted in making flint-glass ; the mechanical and chemical processes being both modified. In flint-glass, we have seen that oxide of lead, for example, was necessary to give density and brilliancy to the material ; but this is not necessary in crown or window-glass, which has only to be looked *through* its body, and not on its surface.

The silica is obtained from a similar sort of sand to that described at p. 547, *ante*. The alkali formerly used was kelp. This is an impure carbonate of soda, procured by burning seaweeds. At one time this was an occupation of considerable importance in the Western islands and west coasts of Scotland. Macculloch thus describes the operation ; for it has become an occupation of historical rather than of technological interest ; soda made from common salt being now far cheaper, and also infinitely purer. In fact, having visited most parts of the coasts of Scotland, both east and west, the only relic of kelp, or salt-making from seaweed and salt water, is the frequent local term of "The Pans," applied to places where such articles were once made. Dr. Macculloch observes—"The kelp season had now commenced, and the whole shore was one continued line of fires ; the grey smoke streaming away from each on the surface of the water, till, mixing with the breeze, it diffused its odoriferous haze over all the surrounding atmosphere. The weeds being cut by the sickle at low water [and they abound to an enormous extent], are brought on shore by a very simple and ingenious process. A rope of heath or birch is laid beyond them, and the ends being carried up beyond high-water-mark, the whole floats as the tide rises, and thus, by shortening the ropes, is compelled to settle above the wash of the sea, whence it is conveyed to dry land on horseback. The more quickly it is dried the better the produce ; and, when dry, it is burned in coffers, generally constructed with stone, sometimes merely excavated in the earth. As twenty-four tons of weed, at a medium, are required to form a ton of kelp, it is easy to conceive the labour employed for this quantity in the several processes of cutting, landing, carrying, drying, stacking, and burning." Such is an account of an industrial occupation formerly of the utmost importance to the soap and glass trades, but now almost entirely given up.

The materials being mixed together, are exposed to an operation called fritting, which consists in calcining them to drive off carbonic acid gas, which thus renders the alkali caustic. The frit thus produced is mixed with old broken glass, and put into the melting-pot, where it is brought into fusion in a furnace somewhat differently arranged to that already described at p. 548, *ante*. Any impurity, as it arises, is removed; and when complete fusion is effected, the metal is ready for a very interesting and scientific process of manufacture.

Instead of being blown and rolled, as described for flint-glass at p. 549, *ante*, a quantity of the "metal" is gathered at the end of a rod, by successive immersions of one of its ends into the melting-pot, and cooling between each dipping, so that a mass of glass may be accumulated on it to the extent of about ten pounds. For a few moments the mass is held vertically, then rolled on a slab, and afterwards blown into a hollow globe. The blowing, after heating, is repeated two or three times; and, after the blowing, the mass is caused to rotate. It is then transferred to the pontil or punty, as shown in the following engraving.

Fig. 408.—Making Crown-glass.

The next step is to "flash" the glass; or, in other words, to reduce it to a thin, flat, circular plate. This is effected by holding the glass before a hot furnace, so that it may be reduced to, and kept in, a semi-fluid condition. It gradually becomes softer, and the globe, at the same time, flattens. It at length bursts out into a flat circular sheet, as represented in the following cut; in which the sheet will be noticed as being held, by the workman, by the punty before the furnace mouth. The plate is then removed, and placed on a bed of sand; and, by means of a cold, wet iron, brought to touch the glass at the point where it is connected with the iron, that connection is severed, leaving what is called the punty-mark—an elevated portion of glass at the centre of the plate. This portion is often used to glaze the windows of out-houses,

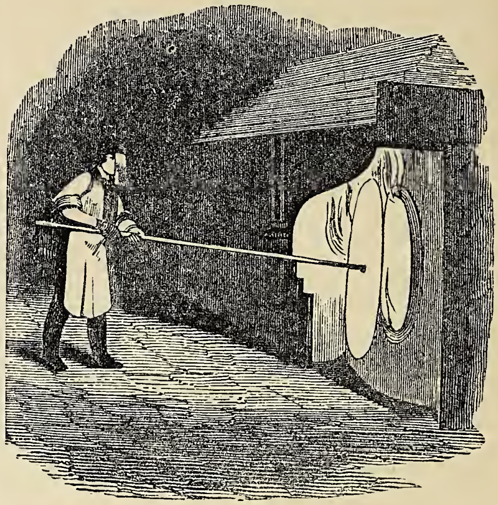


Fig. 409.—Making Crown-glass.

where our readers may have frequently noticed it as somewhat resembling a lens in shape.

After this the plate is removed to the annealing oven; and, after cooling, is cut up, with the ordinary cutting diamond, into squares for the use of the glazier.

We first witnessed this process at a large manufacturer's in the north of England, some twenty-five years ago; and must own that a familiarity with the wonders of nearly every branch of manufacture since that, has not diminished the feeling of surprise at the dexterity with which this process is carried on. Of course, few of the workmen employed at all understand the philosophy of the process; but long experience and practice enable them to supply all lack of science. The success of the operation requires that great judgment should be exercised at each stage of the process. A certain temperature is requisite, below which the ability to expand the glass would fail, and above which the rotatory and blowing actions would proceed too rapidly. The mechanical operation depends, for its success, on an adaptation of the law of centrifugal force, by virtue of which all bodies tend to fly from a centre into space. It is by ingeniously and dexterously obeying this law in the rotation of the globe, and, at the same time, carefully attending to the temperature, that this crown or window-glass is susceptible of being manufactured so cheaply and successfully.

At one time, when the duty was charged on all kinds of glass, it pressed heavily on the makers of crown-glass especially. Each re-melting was charged; and so if the workman broke or spoiled a plate, and its material had to be re-melted, of course he had to pay double duty; and it might, by accident, become trebled or quadrupled from such causes. Hence there was no encouragement held out to improved pro-

cesses of manufacture. On the contrary, as even a small experiment could not be carried on without being liable to duty, the maker dared not, for his own pecuniary interest, venture on the expense that he would have incurred. To this, and to an equally iniquitous tax—the window duty—may be laid the fact that, in the poorer portions of towns in our manufacturing districts, even at the present day, in old tenaments only one small window is found in a room. In the Report of the Census Commissioners for Scotland, in 1861, it is stated that thousands of people in the whole country, have not a single window in the room frequently occupied by a family. We have seen instances of the same in Glasgow, Edinburgh, Manchester, and Liverpool; and, from such circumstances, it is no wonder that there are dens inhabited by human beings whence fever flows in a deathly stream, not only destroying the poorer classes, but extending its maleficent influence to those who are better housed.

The abolition of duty on windows and crown-glass, has had two remarkable effects in a commercial point of view. In the first place, the price of window or crown-glass has been reduced to an almost nominal figure; so that a window that formerly cost shillings per pane in glazing, may be now done at as many pence. Secondly, as the manufacturers are now free from duty-paying and excise supervision, they have been able to turn their attention to improvements of every kind; and thus glass, thinner than the old kind of crown-glass, is made into sheets much larger than, on an average, were those of plate-glass made a quarter of a century ago. The secondary effect of these results also influences other trades. A builder found that a considerable item in the expense of completing a house, was that of sashing and glazing; hence the windows were made small, and few and far between. On the repeal of the glass duty, the lowered price of glass induced an extended provision of windows in new-built houses. This reacted on another branch of trade; and now sashes for windows, instead of being made by hand, are largely produced at a much cheaper rate by machinery; and any amount of houses may be fitted simultaneously, if of one style of building, in a fraction of the time that was once required.

Plate-glass.—Although an extended use of plate-glass has been of comparatively recent adoption, nearly two centuries have elapsed since the second Duke of Buckingham established a manufactory for producing it at Lambeth. But this was found to be an unprofitable speculation, and the first really efficient manufacture in England was made by the formation of the company of British plate-glass manufacturers, about the year 1773, as already noticed.

It is said that the Venetians were the first to bring the plate-glass manufacture to anything like "perfection," and it was to them that the Duke of Buckingham was indebted for any modicum of success that attended his adventure. But it was within the period of the present century only that the manufacture of plate-glass attained even respectability. As regards price, in our earlier days it was enormous. We have a lively remembrance of having to pay a weekly sum at school to replace a piece of plate-glass, ten inches by eight, that formed the covering of a model lead-pencil drawing; the piece of plate-glass being valued at eight shillings!

The extent, or rather, area, of a large piece of plate-glass, entirely prevents the ordinary mode of blowing to be resorted to, as in crown-glass; hence the operation of casting is adopted. In respect to the materials, they barely differ from those already described—namely, fine sand, alkali, and a portion of lead, the proportions of which vary, but not materially, with different manufacturers. "Fritting," or a previous partial melting, is had recourse to, as in the manufacture of common window or crown-glass. The frit is then melted in pots or crucibles, great care being taken that the "metal" is homogeneous; for the beauty of plate-glass depends, not only on its polish and freedom from *striæ*, but also on the entire absence of specks, that are caused by imperfect melting. The methods of discovering any possible chance of imperfection of the material are numerous; but, perhaps, one of the best is that of casting a portion of it; and such quantities thus examined that are considered fit for the purpose are transferred to another pot, to be re-melted, so as to afford as pure a material as possible.

This operation is one of considerable delicacy. As much of the examined glass as is required for one casting is melted at once, and, after complete fusion, it is allowed to cool to an extent that makes it resemble a kind of pasty condition. The metal is then transferred to a *cuvette*, a large vessel, from which it is then poured on to the casting-table. "These were originally made of copper; but, in consequence of this metal being found liable to crack, from the sudden accession of heat that accompanies the pouring over of such a torrent of melted glass, the British Plate-glass Company determined to make a trial of iron, and had a table made which has fully answered the intended purpose, having, during several years of constant use, stood uninjured throughout all the violent and sudden alternations of temperature to which it is exposed. The table is so massive, weighing nearly fourteen tons, that it became necessary to construct a carriage purposely for its conveyance from the iron-foundry to the glass-house." This quotation is from the remarks of the late Mr. Barlow's description of plate-glass-making forty years ago; and, together with the prices that then ruled, will amuse many of the makers of plate-glass at the present day.

The glass being poured on to the casting-plate, is rolled, to bring it to an even surface; and, of course, the table is kept perfectly horizontal. On cooling into a solid mass, the plate is then annealed in a manner similar to that already described in respect to flint-glass, at p. 550, *ante*, modified, however, on account of the particular shape of the plate; but in nowise differing in principle.

The annealing, of course, takes a considerable length of time, even some days; and the succeeding process is that of polishing the surface. This is effected by first grinding the glass roughly with sand, one plate being superimposed on the other. A kind of level surface being thus produced on both sides by changing the respective surfaces face to face, the roughness is successively lessened by grinding with emery of gradually-increasing degrees of fineness. The last operation is that of polishing, which is effected by wood covered with cloth, on which is polishing-paste (putty-powder, or oxide of tin), that is rubbed over the surface until a high polish is attained.

The size of the plate-glass now sold would seem marvellous to the early makers; but constant improvements are effected. The visitors to the London Exhibition of 1862, will, doubtless, remember some fine specimens of English and French manufacture; but especially the latter.

A large amount of plate-glass is used for forming looking-glasses, or mirrors; and these are amongst the articles in greatest demand in the glass trade, although they more particularly belong to the department of the upholsterer or cabinet-maker.

In former times, metallic mirrors alone were used; but, of course, the polish of all but the precious metals was soon deteriorated by oxidation of the surface. Electro-metallurgy was then unknown; and, consequently, only silver or gold could be polished so as to present a permanent reflecting surface.

The "silvering" of glass is performed chiefly by one method only; that is, by backing the glass with an amalgam of mercury and tin. This plan of mirror-making we shall presently describe in detail; but, before doing so, it will be necessary to name a very ingenious method, the effects of which depend on the combined action of light and chemical affinity.

If a solution of nitrate of silver be poured into any clean glass vessel, and a few drops of oil of cloves, or other strong essential oil, be added, the oxide of silver becomes deoxidised by the action of light; and, in the end, metallic silver is precipitated on the surface of the glass. But this must be scrupulously clean, otherwise the result will be marred, if not entirely prevented. The philosophy of the process is exceedingly simple; for the oxygen of the oxide of silver, in the nitrate, combines with the hydrogen of the essential oil; and, consequently, the metal becomes deposited in what we may popularly call its natural form.

"Silvering" glass, as performed by looking-glass-makers, is an entirely different affair, and chiefly mechanical in its nature; although, according to what may be now termed the ruling opinion in science, an amalgam, to be perfect in its character, should be a compound subject to the laws of definite chemical affinity.

The practical process is as follows:—The looking-glass-maker has a long level stone or slate slab, supported by a strong frame; but, at the same time, whilst ordinarily horizontal, can be adjusted at any desired angle by means of a large-wormed screw that raises or depresses one end of it as required. The glass is first very carefully cleaned on the side that is to be coated with the amalgam. The latter is made by spreading evenly a sheet of tin foil, of a size corresponding to the looking-glass that is to be made, on the slab just referred to. On this mercury, or quicksilver, is spread by means of a hare's foot, or other arrangement capable of diffusing it equably over the whole surface of the foil, with which it forms an amalgam having strong reflective powers. The fluidity of quicksilver, and its slight tendency to oxidation, if pure, both favour its use for this purpose.

The plate of glass, carefully cleaned, especially from grease, is then slid on to the sheet of mercury tin foil; and, as much as possible, all air-bubbles are carefully driven off; for these, if present, would spoil the even reflective surface of the intended looking-glass. The glass having covered the whole surface of the foil, cut, as already stated, to the size of the glass, the last is left in contact with the amalgam; being also loaded with weights, so as to enforce, as far as possible, a complete adhesion between the two. After two or three days, the amalgam becomes firmly attached to the glass, which is then tilted on its edge, and so gradually drained of any superfluous mercury. The remaining operation of fitting it into a frame, completes the business of the looking-glass manufacturer.

Bottle-glass.—This is the coarsest of all departments of the glass manufacture; but, at the same time, is not to be despised. In fact, we believe that, if any statistical information could be satisfactorily arrived at, it would exceed, in respect to the production in *quantity,* any other branch of the glass trade.

For example, every hotel, tavern, public-house, chemist's shop, perfumers', and many other trades, depend entirely on the glass bottle; and as no parts of our country, and, perhaps, no other country, are specially celebrated for total abstinence from such liquors; further, as all such bottles, with few exceptions, weigh heavy, the bottle-glass trade must necessarily assume a position of importance. Yet generally, and even in its scientific aspect, this trade falls under the ban of Horace—

> "Odi profanum vulgus, et arceo."

But the methods adopted in some departments of the "bottle" trade, are also followed, for cheapness' sake, in producing tumblers, decanters, jugs, and other vessels, represented in former days by the more expensive articles of cut flint-glass. Thirty years ago, a glass tumbler holding half a pint would have cost something like a shilling at least; but the cast-tumblers of the present day are sold retail at an eighth of the price. It is no uncommon sight, now-a-days, to see a new grocer's or baker's shop opened with the advertisement, that a purchaser of goods to the value of one shilling, shall receive in addition, gratis, a glass cream-jug and a sugar-basin, both large enough for the use of a "four in family." Thus, of late years, times have indeed changed, and we with them (*tempora*

mutantur, &c.) Now this is all due to an extension of the methods formerly and newly adopted in the bottle trade, which we shall here briefly describe.

The bottles formed in moulds, such as are commonly used in perfumery, &c., are made in a very simple manner. In the following cut the moulds and the operation are illustrated

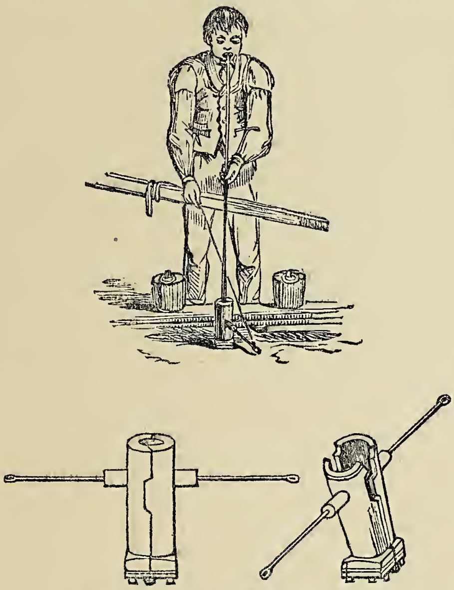


Fig. 410.—Glass Bottle-casting.

together. The workman takes a portion of glass on the end of the blowing-iron, from the crucible, and rolls it in the manner already described at p. 549, *ante*, forming, at the same time, a kind of incipient neck. The cylindrical mass so formed is introduced into a brass mould, two illustrations of which are shown in the preceding cut, below that representing the workman in the act of blowing. By this, after the hot glass has been introduced into the mould, it is spread over the interior of the latter, and so assumes the reverse of its form, the interior of the mould giving form to the exterior of the bottle. Green bottle-glass "blowing," for making ale and wine bottles, partakes partly of blowing and moulding. Thus in the following cut the blowing operation is represented, just at the point at which the neck is formed. By introducing the hot glass into a mould, and blowing, the operation is completed.

Sheet-glass, Tiles, &c.—A large variety of sheet-glass has been brought out since the abolition of the duty; but many new methods have been supplemented to those of older and longer practice; hence, by these a substitute is frequently produced, and at a cheap price, for crown and plate-glass; also for tiles to take the place of the common clay tile, but having the advantage of allowing the ingress of light on a roof or other place; glass slabs, now so commonly used to form part even of the street pavement over grids, cellar-flaps, and the like; thick glass plate, translucent but not transparent, and largely used for windows in factories, workshops, beneath shop windows, to

Fig. 411.—Bottle-blowing.

light up cellars or kitchens, and for a variety of other purposes, in which great strength and semi-transparency are alike of value.

The Crystal Palace at Sydenham is, perhaps, the largest illustration of the use of such glass that we can mention. The quantity of glass contained in it is enormous. It was constructed from the remains of the Crystal Palace of 1851, that contained the exhibition of that year in Hyde Park. The glass used in that construction had a total area of about 1,000,000 square or superficial feet, having a weight of about 400 tons. It was composed of British sheet-glass.

Sheet-glass of this kind is manufactured as follows:—A quantity of glass is gathered on the end of a blowing-tube, and a hollow globe is formed of about ten inches in diameter. By considerable dexterity, it is converted into a cylinder about four feet long, and eight to ten inches in diameter, as shown in the following engraving. Both ends, in this form, are closed, except where the inside of the blowing-tube communicates with the inside of the cylinder. By heating the larger end, and closing the small, the air contained in the cylinder bursts the wide end, which soon attains the cylindrical form common to the rest of the tube, and leaves the wide end open, being also rotated by the hands of the workman. The blowing-iron is then detached from the narrow or neck end, and the cylinder has pressed against one part of it internally and longitudinally, when cool, a hot iron wire. This causes a crack from one end to the other. In this condition the cylinder is placed in a hot oven, with the slit upwards, and gradually it softens and falls down, producing a long, flat sheet. After being rubbed with some charred wood, to flatten the upper surface equally, it is taken to the annealing oven. The

material of this glass is generally inferior to all others, except bottle-glass; but as it is usually

Fig. 412.—Sheet Glass-making.

made thick, and only required for coarse purposes, this is not a matter of objection to its sale or use.

There are numerous other methods of utilising and producing glass that might be recounted, but what have been already described are sufficient to give a general idea, with many specific details, of the glass manufacture in general.

Glass-blowing, for making philosophical instruments, is generally carried on as an entirely separate branch of business; and in London is, to a large extent, limited to one district, in the neighbourhood of Leather Lane and Hatton Garden, London, where the makers of barometers, thermometers, &c., &c., are very numerous. Looking-glasses are largely produced in the same neighbourhood; as is also tin foil, so essential to that branch of manufacture. Glass tube-making, and drawing glass into fine fibre, called glass-spinning, are other occupations connected with the glass trade. The ductility of glass is so great when heated, that it may be drawn into a thread, almost invisible to the naked eye. This is easily effected by taking a flat piece of thin glass, or a glass tube of small bore, and heating it to a red heat. The glass should be held one end in each hand, and drawn out to a thin thread. One end of the glass is then affixed to a wheel, whilst the other is held in the hand. Heat is applied to the glass, between the two extremities; and if the wheel be then rapidly turned, the glass may be spun off in a fine thread with almost any degree of rapidity. By using various coloured tubes, the glass thread will, of course, have corresponding tints. Some years ago attempts were made to utilise this by weaving the thread into cloth; but it was found that the extremely fine ends of the glass had a most unpleasant effect on the skin of the weaver.

There are two arts closely connected with the manufacture of glass, but carried on as a separate branch of trade. They are, the making of artificial gems, and that of enamelling. In paste, or artificial gem-making, the colouring matter is generally the same as that used in producing stained or painted glass; but the glass itself is made of various materials capable of affording high refractive power where possible. Thus some "Paris diamonds" have such brilliancy and high refraction as almost to equal in appearance the real gem. Similarly, the emerald, ruby, &c., &c., are very successfully imitated. A most ingenious method was discovered some years ago, by which the powdered scales of small fish, being spread over the inside of little glass globes, are used to imitate, almost to perfection, the pearl. The cheap form of jewelry, "warranted to contain real stones," is manufactured by such materials; and the complete manner in which both the real gold and stones are imitated, is such as to deceive all but the practical eye and chemical analysis.

The art of enamelling dates, at least, from the time of the Egyptians; and was generally known, at a subsequent date, to the Greeks, Romans, Saxons, &c. It consists in coating a metallic surface with an opaque vitrified coat; and, as the metal has to be exposed to an intense heat, copper, silver, and gold are chiefly used as the base or ground. The oxides of lead, tin, and arsenic, when melted with the usual materials of glass, afford, on fusion together, a white opaque mass. This forms the enamel, which is afterwards ground to a fine powder, and carefully washed, so as to gather only the finest particles, which remain for some time suspended as a milky-looking mass in the water. From this the enamel deposits as an impalpable powder. It is then spread on the metal, and introduced on a muffle into a furnace to undergo firing; here it becomes fused, and spread over the metal. Polishing completes the process.

CHAPTER XV.

GAS, OILS, FATS, PARAFFIN, AND OTHER SOURCES OF ARTIFICIAL LIGHT.

THE early history of the various sources of Artificial Light has been fully given in the Intro. duction, at from pages lxv. to lxxvii.; it will therefore be unnecessary to enter again on this subject. We therefore at once proceed to discuss its details.

Principles of Artificial Illumination.—Practically, all modern methods of artificial illumination are resolved into the combustion of fluids or gases, composed essentially of carbon and hydrogen; for the electric, lime, magnesium, and other "lights," are of comparatively limited use, although, under certain circumstances, of great and increasing value.

It is hardly worth while to enter into a lengthened discussion of the terms combustible, combustion, &c. Many theories have been advanced in respect thereto; but, after all, nothing has been definitely settled, and, prophetically, we shall add—never will be. The reason we assign for expressing so definite an opinion, is this. Combustion, as ordinarily carried on, and viewed in its simple scientific aspects, is, categorically, only to be understood as the setting free of light and heat by the union of two or more bodies. Thus charcoal, or carbon, uniting with oxygen; hydrogen with oxygen; many of the metals with oxygen or chlorine—all afford light and heat, under proper or chosen circumstances, at the moment of their union. But in all such, and numerous other cases, we cannot decide whether the carbon, &c., or the oxygen, is the combustible. Regarding the matter in a purely scientific view, we should consider that, when carbon or charcoal affords, as commonly supposed, heat and light during burning, the source of these two forces is oxygen; because, being the gaseous or lighter material, it becomes condensed, and hence parts with its latent light and heat during the operation of combining with carbon to form carbonic acid gas. But if light and heat are obtained by the union of hydrogen and oxygen, it is far more philosophical to suppose that, in this case, the hydrogen is the source of light and heat; because, being the least dense of the two gases, it must undergo most compression, and, consequently, lose, in that or some other proportion, most heat, if not light.

Practically, in respect to the amount of heat afforded, the opinion we have expressed is generally acknowledged as correct; for no source of heat, except that of the concentrated rays of the sun, equals in intensity that afforded by the combustion of oxygen and hydrogen. But this combustion of these gases or bodies affords scarcely any light. In fact, the purer they are used, the less light they afford during combustion. If, however, solid matter, like lime or magnesia, be introduced into the flame, they produce then, with the exception of the electric light, the most brilliant illuminating of all artificial agents.

A curious and instructive instance of how far solids affect both the colour and intensity of light is found in the electric arc produced by voltaic or dynamic electricity, a subject of which we shall have much to say, when dealing individually with the electric light. Copper terminals give a fine green flame, as do also those of silver. Charcoal terminals give a magnificent white light. But in these cases actual combustion is not necessary, although it is accessory to producing the effect, which simply is due to the rapid passage of minute particles of the terminals through an intensely heated medium.

Hence a kind of dilemma is forced on scientific men. The union of two gases by heat affords no light; but the union of a solid and a gas, or of a gas + solid and a gas, affords abundant light; the latter condition being that of all oils, paraffin and coal-gas; for they contain hydrogen, *the gas;* carbon, *the solid*, and oxygen as found in the atmosphere, by their combining with which, the effects of all ordinary means of artificial illumination are afforded.

It will, therefore, be evident, that to attempt to produce any probably true theory of combustion in the present state of chemical science, is simply impossible, at least with any degree of accuracy. We are not sure, at the present day, whether hydrogen is combustible in oxygen, or the latter in hydrogen. Thus, when a bell-jar is filled with hydrogen, and the lower surface of the gas be ignited, if a jet of oxygen be carefully introduced, the latter gas will appear to be the combustible, and the hydrogen the supporter of combustion. On the other hand, if a jar be filled with oxygen, and an ignited jet of hydrogen be introduced into it, the hydrogen will appear to be the combustible, and the oxygen the supporter of combustion.

From such facts and considerations we can conclude ourselves to be in a state of all but absolute ignorance in respect to the cause of combustion. If, therefore, philosophically, we cannot decide this question, it is quite pardonable to take the popular view of the question, and to consider oxygen, practically, as the *supporter of combustion;* and that other substances, such as hydrogen, carbon, sulphur, and many of the metals, together with combinations

of carbon and hydrogen—as in wood, oils, coal, coal-gas, &c., &c.—are combustibles. This view will be the basis of all our explanations, right or wrong, in the following pages.

Whatever theory may be adopted in respect to the nature of combustion, it will be readily admitted that the light and heat emitted, whether in the burning of oil, gas, or any other substance, arise from what had been previously latent becoming sensible or perceived. Thus, two pieces of wood, at ordinary temperatures, afford no sign of either light or heat being present in, or obtainable from, them ; but on violent friction, as described at page lxv. in the Introduction, when discussing the usual modes, ancient and modern, of obtaining a light, it is well known that both light and heat are easily evolved. The sparks and heat obtained by forcing down the railway break on a wheel, by the knife-grinder's machine, the flint and steel of former use, and many other contrivances, illustrate the fact, that all bodies, no matter whether they be gases, liquids, or solids, have the power of affording us those forces. Even cold water or ice may be made to yield heat and light ; for when in contact with the metal potassium, both these forces are simultaneously evolved.

But it is not in every instance that these forces are at the same time produced ; and the great secret in the art of artificial illumination is, so to arrange the one as to produce the other. Heat is the force generally employed to evolve light in all artificial arrangements entered into for that purpose.

If we inquire into the conditions absolutely essential for the combined evolution of heat and light, it will be found that the presence of matter in a solid condition is invariably necessary. It has been already pointed out that the simple combustion of hydrogen and oxygen affords little or no light. In this case no matter of a solid nature is present, and consequently, as we shall presently explain, no light is afforded sufficient to produce what is generally considered to have an illuminating effect.

The principle here involved may be conveniently studied by two very simple experiments. In the annexed cut is represented a bottle, containing some iron or zinc nails, and nearly filled with a mixture of water, to which an eighth part, by measure, of sulphuric acid has been added. The neck of the bottle is fitted with a cork, in which a glass tube, drawn to a point, is fixed. After adding the acid to the metal, replacing the cork and jet, and allowing the mixture of air and hydrogen to escape a short time, to prevent danger of explosion—if a light be then applied to the jet, the hydrogen afforded by the decomposition of the water will inflame, and give a pale reddish-yellow light, affording no illuminating power. If, however, a piece of platina foil be held in the jet of burning gas, a large amount of light will be at once produced. Or if a few iron-filings be scattered through a sieve into the flame, as illustrated by the annexed cut, then a brilliant white light, of strong illuminative power, will be afforded.

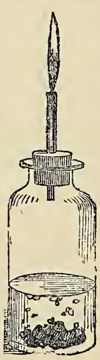


Fig. 413.

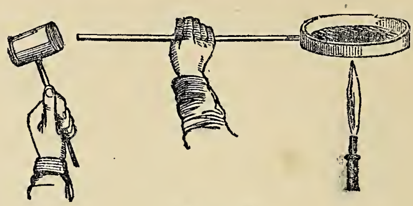


Fig. 414.

In both of these simple experiments, the light produced results solely from the presence of matter in a solid condition, *incandescent* in the flame. Here it must be pointed out that *incandescence* is a very different condition from combustion, or burning. In the former state of incandescence, matter remains for hours, or even years, without change, as in the case of the platina foil in the jet of hydrogen, already referred to as the earliest of the experiments we have suggested : but the iron-filings undergo combustion ; that is, they unite with the oxygen of the atmosphere, to form an oxide of iron, lose their metallic form, and, at the same time, being greatly diminished in specific gravity, affording both light and heat, previously latent in them.

It is from a precisely identical cause that all our ordinary illuminating agents afford light and heat simultaneously ; but the substance differs from those previously named. It is carbon, present in oils, coal-gas, paraffin, &c., which gives them their illuminating power ; whilst the hydrogen they contain is the chief source of heat. And so strictly is this true, that in the manufacture of gas, as an illuminating agent, nothing is so essential to its value, in regard to its lighting powers, as the presence of a due proportion of carbon united chemically with the hydrogen.

For example, at the time of penning these lines, there is laying before us the last weekly report of several gas inspectors of different portions of the metropolis, in which complaint is made that a certain supply does not exceed a twelve or thirteen-candle ratio ; in other words, a definite quantity of gas, during combustion, as supplied to the customer, affords no more light than is supplied by twelve or thirteen sperm candles of a settled standard size and rate of combustion. But, at the same time, Glasgow is supplied with a twenty to a thirty-candle gas ; or, in other words, supposing that precisely the same prices be paid per 100 cubic feet for each gas, the Glasgow consumer really pays only half as much as the London consumer, because he is supplied with a gas of double illuminating power.

The secret of this difference lies in the fact, that the Glasgow gas, made from excellent cannel or parrot coal, is far richer in *hydrocarbons* than the London gas. By the preceding word, *hydrocarbon*, is meant a combination of the

elements hydrogen and carbon, of which there are a great number produced in all illuminating agents, and universally existing in vegetable substances—coal as their fossil, petroleum oils of all kinds, paraffin, &c., &c. The Glasgow, or any other gas, entirely made from cannel, is extremely rich in the possession of this hydro-carbonous material; and, therefore, possessing carbon abundantly in its solid form, affords a much better light-giving gas. Similarly, paraffin, in its solid state, is by far the best ordinary agent for candle-illumination, and now justly sold under the designation of "gas candles;" because, for all practical purposes, it may be considered as neither more nor less than solidified coal-gas of the richest kind, burnt with a wick, instead of, as ordinarily, by a jet.

That carbon is present in all our usual forms of artificial illuminating flames, is easily, and, indeed, too frequently, made evident. A cold plate held in the flame of any candle, lamp, or gas flame is readily coated with a black substance, known as lamp-black, which is carbon in an impure form: and, as we shall subsequently point out, the proper combustion of the carbon present in such flame, together with the proportion of its presence, must be considered as an important condition in estimating the value of any flame. For example, if much carbon be present in any gas, and the flame be thick and abundant in breadth, slow and imperfect combustion will take place, and a lurid red light, with much smoke, will be produced. The gas-lights, in many parts of our large towns, allowed to burn, especially at the outside of butchers' hops, illustrate such a condition. In this case, the carbon, although possibly abundant, is imperfectly burnt; and hence a poor light is afforded. An occasional gust of wind, however, supplying, like the bellows to the fire, more air, and consequently more oxygen, improves and increases the combustion; and at that instant, therefore, an increase of light is afforded.

On the other hand, it frequently happens that, with peculiarly constituted burners, the carbon is overburnt; that is, its combustion is carried on so rapidly and effectually, that the amount of light is much diminished. This occurs chiefly in Argand, or modified Argand gas-lamps, in which a powerful draught urges on the combustion too far; and, as just pointed out, diminishes the amount of light that would, by a moderated management, be afforded.

It will be, therefore, seen that there are many circumstances that must be taken into account in respect to what may be termed the principles of artificial illumination. A certain quantity of hydrogen is necessary to afford heat; of carbon to afford light; and of air, containing as it does oxygen, to generate and maintain combustion.

But, connected with each of these chemical conditions, is another, that involves both chemical and physical laws: we refer to the nature of flame itself.

Apparently this is exceedingly simple; but we shall find much of scientific principle involved in the subject. A candle will afford an excellent means of examining many interesting questions relating to it.

When the wick of a common tallow *dip* candle is lit, and subsequently snuffed, three distinct flames may be seen. That which is external to the chief flame, generally escapes notice of all but those aware of its existence. It is extremely delicate, owing to over-combustion of the carbon, through the abundant access of the oxygen of the external atmosphere. At the lower part of the wick, and nearest the tallow, is the blue flame, the colour of which similarly arises from a high rate of combustion. Above the blue flame, and forming the really illuminating portion, is the white flame, where the combustion of the hydrogen and carbon, or the hydrocarbon, is chiefly carried on. As the combustion proceeds the wick lengthens, and the flame becomes gradually of a yellow colour, tipped with red; and shortly afterwards, the supply of fat by the wick is so much larger than can be properly burnt, that the amount of light is enormously decreased.

On careful examination, it will be found that the flame of such a candle is hollow; and one or two simple experiments only are required to prove this fact. For example, in the annexed cut, the left-hand engraving represents

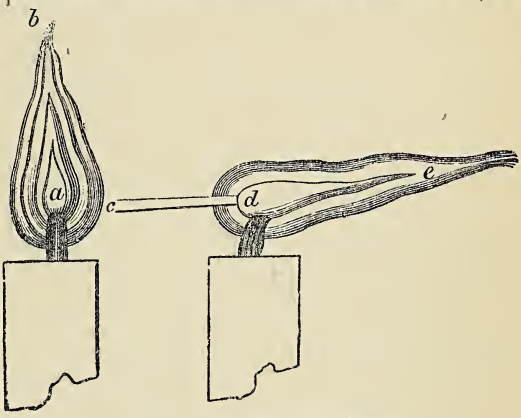


Fig. 415.—Nature of Flame.

a candle in the condition we are now describing. At *a* we notice the interior of the flame, and at *b* its apex or smoky portion. If, however, a pipe, *c*, be inserted in the flame, as from an ordinary blowpipe, and air be driven by the mouth, or any other means, so that it shall have access to the interior portion of the flame, consequently diverging it from the vertical position, *a*, *b*, to a horizontal one, *d*, *e*, as shown in the right-hand engraving, then combustion will go on at the same time both in the inside and on the outside of the flame, and great heat, with much light, will be developed. The interior flame will present a bluish appearance at its apex, *e*, where, like that of the ordinary vertical candle-flame at its blue part, great heat exists. Exterior to this, the illuminating part of the flame, in the horizontal one, will be found.

Another and very simple method of illustrating the hollow character of flame, is that of inserting a small-bore glass tube, about three inches long, into the centre of a candle-flame, just over the wick, holding the tube obliquely, and raised highest at its most distant end from the candle. At this end gas will be seen to issue, that will ignite if a light be applied to it. Now this gas is the unburnt vapour produced by the distillation of the fat, or, more scientifically, of the hydrocarbon constituting that fat.

Some very interesting results, but especially in their practical aspect, have arisen, together with most useful and economical applications, from a due consideration of what has been stated both in respect to gas and oil illumination. It has already been noticed that, at least 2,000 years ago, it was discovered that one wick, split into many branches, and so separated that air can have access to all exterior parts of each, gives much more light than a single wick formed by the union of all. Now this simply arises from the fact that combustion is more rapidly and completely carried on. It will be in the memory of most of our readers, that, several years ago, Palmer's double-wick candle had an enormous sale, both for burning in lamps and as ordinary dip-candles. They were so constructed that the wick split into two portions, or rather, that the wick, being double, diverged to two opposite sides, and exposed a flat flame to the full action of the air, by which combustion was rapidly and effectively carried on, producing a brilliant white light, at least in regard to the usual effect of candles.

Another method, and one which has greatly benefited and extended the candle manufacture, especially as causing the wick to be self-snuffing, is that now always adopted in stearine, paraffin, and other better-class candles, of causing the wick to fall of itself out of the flame, which is thereby rendered comparatively flat, and affording a better light. As is well known, in ordinary dip, or old-fashioned mould candles, the wick gradually lengthens until it overtops the flame—a circumstance resulting in almost the destruction of the light; hence the necessity of constant snuffing of such candles. If, however, a lighted dip or mould be placed in its stick, not vertically, but obliquely, it will be noticed that the red-hot wick, inclined at an angle, will soon get access to the external air, where having arrived, it gradually undergoes combustion, and really thus snuffs itself. The flame, after having attained a certain average, also maintains it in respect to illuminating power, until the candle is entirely consumed.

The plaited wick of the composite and other such candles answers precisely the same purpose. Being flat it has a tendency to curve at its upper end, and so gradually to reach the external air whilst burning. On arriving at the atmosphere it undergoes combustion, that gradually removes all its solid parts as gas and vapour, to which we shall presently draw more particular attention.

The Argand lamp (so named from its inventor) is constructed on precisely the same principles as those just explained. Instead of the wick being solid, it is hollow and cylindrical, and placed around an internal metal tube. Its interior and exterior surfaces both burn, and the flame on either side is therefore exposed to the atmosphere. The result is, of course, a much more complete combustion of the carbon and hydrogen of the oil than by the solid wick; and, consequently, the amount of light is greatly increased. Similar observations apply to the use of the Argand gas-burner, in which the gas, like the burning wick and fuel of the oil-lamp, is exposed, on both its burning sides, to the action of atmospheric air.

All gas-lights and oil-lamps now in use are constructed with regard to this principle, whether they be hollow or flat. For instance, in the bat's-wing, fish-tail, and similar burners, by a peculiar construction or position of the holes supplying the gas for combustion, a thin, flat flame is produced, that permits of the rapid and effective combustion of the gas.

But however completely we may attempt to effect combustion, so as to produce a "good"—that is, a white light—it is impossible, by any ordinary means of combustion of hydrocarbons, to attain anything that can be called better than a yellow, or reddish-yellow light, if we take sun-light as the standard. The nearest approach to the latter is that afforded by the disruptive discharge of a powerful voltaic battery between two pieces of charcoal, separated by a small interval. With powerful arrangements, so near an approximation can be made, in the electric light (as it is called), to the intensity and purity of sunshine, as to leave little to be desired. Of a bluer and more penetrative power is the light produced by burning magnesium wire; and next to these is the lime-light, afforded by causing the flame of oxygen and hydrogen gases to impinge on a cylinder of lime; but even this brilliant light appears red by contrast with the electric light. The combustion of phosphorus in oxygen also affords a comparatively pure and white light.

But we must here explain what we mean by *white light:* for it is evident, that although each of the lights that have been named appears white, they are only so by being compared with their inferiors in that respect. Thus the light of a composite candle is whiter than that of a dip; that of a paraffin candle than one of the composite; and so on through oil and gas-lamps, until we reach the electric and magnesium lights, which rank next to sun-light in purity.

A light is white only when all the constituent colours of light are so completely blended that none exceed the other in power, as viewed by the eye, directly or by reflection. White light, if made to pass through a prism of flint-glass, is decomposed, according to the old idea, into seven colours; but now reduced to three—namely, blue, yellow, and red. All the other four, violet, indigo, green, and orange, may be produced by certain mixtures, in pairs, of the preceding three.

Now, sun-light, on a clear day, with the air as free as possible from moisture, is *white;*

that is, all the component colours of light are so blended in it, that none are predominant. In the light of gas, oil-lamps, and candles, such is not the case. In these the yellow or red, or yellow *and* red, are predominant; and, consequently, all coloured objects viewed by them alone are so seen with an admixture of yellow. Hence, before such lights, all blues become more or less green; it is, therefore, impossible to see such colours by artificial light in the same form or nature which they possess in daylight. The effect of artificial light on fabrics dyed of a magenta, mauve, and some other colours, is very great; entirely, indeed, removing the impression of the beholder that such colours are really before him. For the same reason it is absolutely impossible to match any colour at night by artificial light; for the yellow rays of the latter completely mask the real colours.

This leads us, for a moment, to remark on what is called *monochromatic light.* If some spirits of wine be mixed on a plate with some common salt, and this mixture be set on fire in a room from which all other light is excluded, all surrounding objects will appear of the same colour. For example, if ribbons of different light colours be fixed on a piece of paper, they will all appear of a dirty-yellow colour, resembling that of the flame: the human face simultaneously puts on a ghastly appearance—a circumstance occasionally taken advantage of to heighten the effect of ghost scenes in theatrical and other representations. In the same way baryta affords a green, strontia a red colour; and many metals in combustion may be made to afford this monochromatic, or *single-coloured* light.

From this and the preceding named facts, we can at once perceive how it is that artificial light is defective. It is in part monochromatic; that is, one of its colours (yellow), or often two (the yellow and red) predominate, and produce, partially, a similar effect to that of the burning spirits and salt on surrounding objects. Appreciating such facts, it has been attempted to neutralise these yellow rays, especially in Argand oil and gas-lamps, by using blue or bluish chimney-glasses. These correct or neutralise the excess of yellow rays in the artificial light, and so produce a much whiter light. But they destroy also a portion of the rays, and hence lessen the amount of light afforded; consequently they have only been used for special purposes, as for the illumination of compound microscopes in use with artificial light, &c.

Much popular error exists in respect to colour. It is supposed to be a quality resident in bodies; but that such is not the case will be evident from considering the effect of the monochromatic light, just described, on the colour of the ribbons. But that colour is not inherent in any body, is still more satisfactorily shown on casting the prismatic spectrum on a paper screen, by allowing the rays of the sun to pass through a flint-glass prism. No matter what the colour of the body, it will assume that of the portion of the spectrum if placed therein, and, for the moment, lose its own. Again, oil may be perfectly "white" and transparent; but if dropped on the surface of water, it will gradually spread, and at last become so attenuated as to reflect to the eye every hue of the rainbow; or tar, which is, on the contrary, very black and opaque, will similarly produce such results. On this fact also depend the colours of the feathers of birds, of mother-of-pearl, the soap-bubble, &c., &c.

In this, therefore, we see the reason why all coloured objects afford a different appearance by artificial than by sun-light. They do not reflect to the eye the same colour, simply because, in the former case, the excess of yellow rays interferes to destroy both the colour and quantity of the rays reflected from thence to the eye of the observer. In nature, some beautiful landscape and scenic results arise from the same cause, that may be generally noticed, but which are more especially to be admired in mountainous districts, and best at the rising and setting of the sun, when objects reflect the most gorgeous or sombre tints, according to the circumstances of their illumination by the solar rays, the interference of clouds, and other causes affecting the general colour of light.

Connected with this subject is that of the intensity and penetrative power of light—one of familiar knowledge as to fact, but as yet little understood; and with this we may include the different diffusive characters of various sources of light.

To illustrate these peculiarities, we may institute comparisons in regard to such properties as possessed by the sun and artificial sources of light. No matter how well an apartment may be lit up at about twilight, if the smallest chink exist in a shutter, so that the daylight may creep in at sunrise, its effect is quickly manifested, for sun-light has great penetrative and diffusive power. Under the same circumstances, the penetrative effect of the flash of lightning is well known, as it is proverbially impossible to keep "lightning out of a room." From whatever cause, the electric light obtained between charcoal points, and the spark of the electrical machine and the Leyden jar, are highly penetrative, but not diffusive. They both give intense light, but exceedingly black shadows. So little diffusive power is there even in a most powerful electric light, that whilst the amount of illumination is enormous in direct radiating lines from the charcoal points, any solid opaque body projects a black shadow, utterly unilluminated by diffusion. Hence the great objection to this light for ordinary illuminating purposes; and, in photography, except for "printing," it is impossible to obtain half or modified tones of light and shade. It is remarkable, that in more yellow lights this power of diffusion is greater. Thus, the lime-light diffuses better than the electric light; a gas-light better than the lime-light; and oil-lamps and candles better than the gas. Why this is the case is not yet understood; but the fact is undoubted.

Connected with the penetrative power of light is that of its intensity, by which we mean the illuminating power existing at different

distances from the origin of the light to be measured. As this subject lays at the foundation of the art of *Photometry*, of which we shall have to speak more fully, in regard to its use in estimating the light-giving powers of gas in a commercial point of view, a few explanatory remarks will be desirable.

Forces are called radiating or radial that act, in their effects, from a centre, in curved or straight lines; but all our remarks will refer to the latter condition only, the question of "curved" forces not requiring any consideration here. The mode of radiation may be illustrated by referring to the wheel of a carriage. The centre of the nave may be considered as representing the point in any illuminating body whence the rays of light are emitted, and the spokes will represent the direction or radial lines that the light, heat, electrical, or magnetic rays take in their progress into space. Sound is equally subject to the law of radiation; but we merely name this incidentally, as showing the universality of its operation.

The intensity of light as a radiating force varies as the *square* of the distance *inversely;* by which we mean, that when light has travelled the double of any chosen distance from a body, its intensity is not one-half, but one-fourth, of what it was at the half of the total distance; and it is, consequently, spread over four times as much surface. Thus, a piece of paper a foot square, placed at any distance from a candle, would entirely and exactly cover with its shadow another piece, four feet square, placed at double the distance of the one-foot piece from the candle; at three times the distance a piece nine feet square would be similarly shadowed; for 2×2 is the square of 2, giving 4 as the surface covered, and, consequently, $\frac{1}{4}$th as the measure of intensity; and 3×3 is the square of 3, giving 9 as the surface covered in the second case, with an intensity of but $\frac{1}{9}$th of the one-foot distance; and so on, similarly, for any and every other chosen or possible distance, in the same ratio, as far as the light could reach, by its penetrative power, into space. So far for written description of an exceedingly simple fact; but we recommend an actual trial of the experiment suggested with the candle and paper; for it by no means follows, that whilst a scientific fact is of a simple character to some, that it may be so to all.

These remarks apply to the measurement of one light only; but they are equally applicable to any number; and hence the mode adopted by gas inspectors, called *photometry*, in comparing the light-value of one gas with another, or with some other chosen standard. Without going into the question fully at present, we may briefly detail it so that our unpractical readers may follow many statements that will be made, and which would otherwise be unintelligible to them.

At p. 562, *ante*, when comparing London with Glasgow, and other rich gases, the phrase 12, 20, and 30-candle gas was used, by which the following is meant:—When two lights, of different intensities, are required to be measured, it is evident that the most powerful of them will send an equal amount of light, or, rather, exercise a greater amount of illuminating power, at a distance further than the weaker light could do; and the relative value of them would not be in simple arithmetical proportion, but according to the squares of the two distances. Thus, supposing that the light of the most powerful was equal, at a distance of four feet, to that of the weaker one at two feet, then their relative illuminating power would be as 16 to 4; or the most powerful would have four times the illuminating power of the weaker. Roughly, the method of proceeding would be to so place the lights that they produced an equally deep shadow from a solid object on a screen. Other and more exact methods have been devised, to which reference will be made hereafter.

The above, however, would only give the relative value of the two lights, that would be of little use if compared with those of other lights; and hence a standard is chosen. That which has been fixed on is a sperm candle, burning at the rate of a definite number of grains (say 120) per hour; and sperm is preferred, because, if properly made, it burns very evenly. The gas is burned in a standard burner of certain dimensions, in respect to the number of holes, and other particulars. The method of proceeding is simple, whatever photometer is employed; the only duty being that of so arranging the lights that an equal intense shadow is cast by both, and then calculating, in the method already explained, the relative value, in candles, of the gas examined.

Many questions, which will hereafter be considered at length, might here be briefly dealt with, as involving principles of primary importance in carrying out any system of artificial illumination—of which, however, we must here make but a selection, as introductory to the general subject.

The products of combustion is a question of great importance, especially in respect to sanitary matters; for, of course, all burning substances necessarily deteriorate the air in which they continue in combustion, not only by abstraction of the oxygen, but also by the addition of new forms or combinations, some or all of which may become prejudicial to health.

Whenever gas, oil, or candles are burned, they produce water, and carbonic acid gas abundantly. The water is produced by the combination of the hydrogen of the gas, or other agents, with the oxygen of the atmosphere; and the carbonic acid by the union of the carbon of the gas, &c., also with the atmospheric oxygen. The carbonic acid is well known as a dangerous gas if present in but small quantities in an apartment. On the large scale we recognise its fatal presence in the choke-damp of the mine; as found in deep wells, vats, &c., and consequently as being the frequent cause of fatal accidents. Not that it is absolutely poisonous in all forms; for in beer, champagne, soda-water, and many mineral waters, it affords that sparkling effervescence that renders those beverages delicious. But as a gas inhaled into the lungs it is deadly

poisonous, having a narcotic effect that, by a dreamy unconsciousness, lulls its victim into the sleep of death. Even when very minute quantities are present in a close or badly ventilated room, its effects may speedily become evident, owing to faintness and drowsiness of those breathing it. Hence it is a matter of great consequence, in choosing an illuminating agent, either to have that which affords least carbonic acid during combustion, or to provide suitable ventilation for removing the products of combustion. In the early days of gas, neglect of this precaution engendered much prejudice against its use, independent of the impurities of the gas itself.

The water, as a product, may be generally neglected, except in special circumstances, so far as it alone is concerned; but when we view it in connection with many of the products of gas-combustion, it assumes some importance. Most gas contains, as supplied to the consumer, a proportion of ammonia, sulphur, and even arsenic; and all these, as burnt with the gas, produce new combinations, some of which are injurious alike to health, furniture, books, and other articles usually in houses. This subject will again be considered; but, for the present, we may add that only two methods exist—*prevention* by careful manufacture on the part of the gas companies, and a *remedy* in the adoption of abundant ventilation by the gas engineer or architect.

Another source of sanitary objection to all illuminating agents here dealt with is, that portions of the fuel escape unconsumed. If a gas-light be turned up too high, a portion of the gas escapes unburned; and the peculiar smell in rooms, where oil, or paraffin lamps and candles are burning, arises from the same cause. As a rule, however, and admitting of even moderate ventilation, there is no doubt that gas, as now manufactured in this country, is the most healthy of all artificial illuminating agents.

Practically, however, the reverse is the case, the reasons of which may be briefly stated. Until gas became generally used in our households, a couple of mould candles were considered sufficient to illuminate any ordinary-sized sitting-room, even with all the disadvantages arising from loss of light, caused by the necessity of constant snuffing. The same may be said in respect to composite candles, two of which were always considered sufficient for the same purpose. But these, and all kinds of lamps, afford their light close to the eye of the user; and further, there is an exact limit, beyond which each cannot be made to afford more than a certain amount of light, always regulated by itself in the candle; and practically, also, in the lamp, because if the wick of the latter were turned up too high, of course the flame would smoke, and become excessively annoying.

In the case of gas, however, when introduced into private houses, opposite conditions prevail. A gasalier with two, and frequently three branches and burners, is hung from the ceiling, at some feet distance, over a table where reading or any other occupation is being followed. The lower part of the arms of the gasalier, and glasses, hide or prevent the passage of most of the light, which is consequently diffused over the room, all of which is well lighted, except the part most wanted. Hence all the burners are used at full light, or, at all events, two; and in the latter case, as much light is afforded as would be equal to that of twenty mould or sixteen composite candles; at least eight times as much light, therefore, is used in the room as when candles had been employed.

It follows, that the more gas is burned, the greater are the products of combustion, and the more rapidly does the air of the apartment become vitiated. But another source of evil also arises. When so much gas is burnt, the combustion produces great heat, and, of course, the apartment becomes unnaturally warm; indeed, to those unacquainted with practical details, it may be surprising to relate that, in a close room (that is, one having no means of exit for hot air at the top), if gas be burned, the air near the ceiling may attain a temperature of upwards of 150°, whilst the rest of the room has a much higher temperature than is accordant with the health of its occupants; for it is not simply the exposure, to a high temperature, of the body that is objectionable—the danger lies in moving out of so heated a room into the cooler air of other rooms, passages, &c. In many cases, particularly amongst the working and lower classes in some of our towns, but especially in the manufacturing districts, gas is frequently made to do the work of a common fire in many ways, but chiefly for warming purposes. At night, the door of the room being shut, the gas is left on full for burning, to keep up the heat of the apartment. On two occasions we personally met with instances of this sort: a sleeping apartment, containing from six to eight adults, besides children, cooped up in a room not ten feet square; the gas full burning, and, in both cases, the atmosphere of the rooms poisonous and disgusting, being not respirable by any person entering the places from the outer air. Such instances are typical of hundreds and even thousands of others in the poorer districts of our large towns; but especially in Manchester and Glasgow, where over-crowding in dwellings is consequent on the great localising influence of the cotton manufacture, and others dependent on, or allied with it.

But we have to reconcile what has been before stated—that gas is the most healthy of all ordinary illuminating agents—with the remarks and facts just given. This is easily done. Confining our observations to the gas ordinarily supplied in London, and presuming the use, in a room, of two burners, consuming together ten cubic feet per hour, or five cubic feet each, the heating power produced would be sufficient to raise 4,500 pounds of water one degree in temperature. But if *the same amount of light* be required either from oil-lamps or candles, these, during their combustion, would afford sufficient heat to raise nearly 12,000 pounds of water to one degree of higher temperature; or, in other words,

for the same amount of light, oil-lamps and candles heat a room two and a-half times as much as does gas.

In respect to the vitiating effects of all ordinary illuminating agents, it has been found that gas is by far the least harmful, so far as the production of carbonic acid is concerned. According to Dr. Frankland, ordinary London gas produces but one-half of carbonic acid gas that tallow does during the same period of combustion, and for the same amount of light. In respect to other deleterious gases, &c., given off as sulphur, arsenic, &c., from burning gas, these are generally in far too minute proportions to be appreciable by measure. They are, however, cumulative; that is, the constant burning of gas in the same room continually, produces, for example, sulphuric acid from the combustion of the sulphur or sulphide of carbon in gas; and, at last, the effect becomes evident in the destruction of the colour and texture of furniture, books, and other articles composed of animal and vegetable objects.

All combustible substances require a definite amount of heat to afford light; and this is a point of considerable practical importance, but very recently appreciated to its fullest extent. We have already pointed out that the usual solid metal branches, burners, and other appendages, in connection with the orifice from which gas escapes whilst burning, tend to diminish the amount of light obtained by abstracting a portion of the heat that is required to support full combustion. This fact is familiarly illustrated in ordinary grates, entirely made of iron. It is exceedingly difficult to light a fire in such, if small, because the mass of metal so rapidly conducts the heat from the paper and wood at first kindled. If, however, these be surrounded, before lighting, with cinders, so as to entirely separate them, by the bad-conducting charcoal, from the metal, the fire is much more readily lit. The same result occurs if the back and sides of the grate be lined with fire-brick, which is also a non-conductor.

Formerly, the ordinary Argand gas-burner was a heavy cylinder of brass, an inch or two deep. One of the greatest improvements in this form of burner was to reduce it to a mere ring, and, at the same time, to diminish, as much as possible, the fittings on which the glass chimney was held. This was done on the principle already described—that of removing, to the fullest extent, all means by which the heat necessary to support combustion could be conducted or carried away. The introduction of clay or porcelain burners was another and valuable step in the right direction, having precisely the same effects as those of the fire-clay "backs" to grates—viz., an economy of heat, and, consequently, in the case of the gas-burners, an economy of gas. In an instance that came under our notice some years ago, the substitution of light for heavy gas-fittings, effected a saving of about one-third of the gas previously burned; and better light was afforded, because the lighter appendages of the burner caused less shadow and general obstruction of light.

The preceding facts suggest some curious analogies which subsist between our mode of obtaining artificial light by lamps and candles, and that of our heating arrangements of general use. In the Argand gas or oil-burner we have precisely an analogous set of contrivances that we employ in domestic heating. The chimney of the lamp corresponds to that of the fire-place, both causing an upward draught to produce vivid combustion. If either be made too high, equally the gas of the lamp, and the coals of the grate, are rapidly and uselessly burned away; and, on the other nand, if they are too low, the combustion goes on imperfectly. A contraction in the neck of the lamp-chimney, as in the upraised part, or register of the fire-place, is equally advantageous in increasing the available amount of light from the lamp, and of heat from the fire-place.

In respect to the production of light by gas, oil-lamps, and candles, philosophically the processes are identical. In the case of gas, the distillation is carried on at a distance—even miles away—from the light; whilst, in oil-lamps and candles, each carries on its coal or fuel distillation at the point of combustion. But the result, in each case, is identical; for the solid or fluid hydrocarbons are heated and separated to undergo combustion, which only takes place at the spot where the light is afforded.

Whilst noticing the generl principle of artificial illumination, a few words may be said in regard to the philosophy of the wick of the oil-lamp and candle.

And first it is to be noticed, that precisely the same force, or principle, is involved in these that we see in operation throughout animated nature. The ascent and circulation of the sap in plants, of blood in animals, and of the oil in the lamp, or candle by the wick, all depend upon one force, called *capillary attraction*. This attraction differs from all others as being exerted on the surfaces of bodies; and the principles of its action may be familiarly illustrated as follows:—

If two pieces of window-glass, say each three inches square, and quite clean, be immersed, to the extent of an inch, in a plateful of water; and they are so placed that, at one end, they touch from top to bottom, whilst at the other they are separated to the extent of a quarter of an inch, the water will rise, at that end where they touch, considerably above its level in the plate, and gradually descend until, at the open end of the glasses, it is at an equal height both inside and outside of them: a curve will be formed, of the shape of a portion of a parabola; and the shape of this curve, its dimensions, &c., may be used as a measure of the force of capillary attraction thus in operation.

Again, if a piece of loaf-sugar be placed in water so that its lower end only shall touch the fluid, yet the water, by virtue of this capillary attraction, will speedily rise and saturate every part—a fact familiarly known and seen at the tea-table.

Lastly, if a number of glass tubes, of diameters varying from the one-hundredth to an eighth of

an inch in the bore, be immersed at a little distance from each other in water, the liquid will rise highest above its level in those of small-bore, and less progressively in each down the largest bore. From this fact—the rise of fluid, in extremely fine tubes, above its ordinary level, as in hairs *(Lat., Capillus)*—the term *capillary* attraction has been derived.

Now the wick of the lamp or candle, and the dust outside a lamp, or any vessel containing oil, act precisely on the principle just elucidated. It is well known that even a dry wick, as placed ordinarily in an oil or paraffin lamp, although its top may be three or more inches above the level of the fluid, will soon become permeated with oil to its uppermost edge, where combustion is carried on; and when the lamp or candle is lighted, this up-drawing process will go on until all the oil or tallow is consumed. This operation may be easily noticed in an ordinary dip-candle while burning, for the melted fat will be seen rushing upwards, in minute globules, to the black part of the wick, there to undergo distillation and combustion.

The completeness of this capillary process, by which the oil or melted fat is thus raised in the lamp or candle, will be affected by the quality of the wick itself; and this depends also on the quality of the cotton, and the mode of its manufacture. In an early attempt to produce a self-snuffing tallow candle, about forty years ago, we had spun up every variety of raw cotton at that time imported into England. The tallow-chandlers of that day were all fully aware that great difference existed in various kinds of cotton; so much so, that they gave prices varying from ninepence to two shillings per pound to form the wick of candles; and the manufacturers of lamp-wicks were equally careful to choose a suitable cotton, irrespective of price, for the best class of goods.

Examining the different specimens of cotton just named by the microscope, we found that those in which the individual filaments were most hairy, were those best calculated to form a good absorber and capillary wick; for each additional hair, stretching out like a bristle from the yarn, gave in itself a capillary organ, and so facilitated the rise of the oil in the lamp, or the fat of the wick. The cotton, imported largely at times from Smyrna, and sold as "Turkey," was most valuable for candle-wick; although, from its roughness, barely suitable to make cylindrical wicks for Argand lamps, because it frayed away so rapidly in the loom.

To confirm the opinion that the coarse open hair or filamentous cotton was the best, by means not here necessary to relate, we burst open the fibre of the silky American and some Egyptian cottons, that, in their ordinary condition, burn badly. When thus opened out, and their exterior surface made bristly and hair-like, as is the Smyrna cotton, their burning qualities were astonishingly improved. By similarly acting on the cotton supplying the plaited wick of composite candles, a still more marked advantage resulted.

But, besides the mechanical, the chemical properties of the wick are important. Some kinds contain much earthy matter, but especially such as have been bleached by chloride of lime; for during the bleaching process much sulphate of lime is formed, that greatly militates against complete and proper combustion; besides which, the mineral substance is brought to the edge of the wick, whether in the crust of the lamp or the consuming end of the self-snuffing candle.

It will be thus seen that there are many conditions requisite to be attended to, even in the apparently trifling matter of a lamp or candle-wick. Commercially, in fact, the matter is of great importance; and we have known instances of persons being completely ruined in the trades connected with lamps and candles, simply from want of an adequate knowledge of the principles here laid down. Indeed, there is no branch of human occupation that does not, to a greater or less extent, depend on the application of science; and the more carefully its principles are attended to, the greater amount of success, pecuniary and in respect to reputation, may any one expect to reap.

It will be unnecessary for us to enter into any description of certain chemical properties or qualities requisite in the oils or fats used for lamps and candles. At a previous page, a general statement has been made of those special qualities they possess; and a more minute detail of their characters, sources, &c., will be reserved for separate consideration hereafter.

Last in the general principles that influence all kinds of ordinary artificial illumination, we may mention that the pressure, temperature, and moisture, or hygrometric state of the atmosphere, have great influence on the amount of light which, with all proper and possible care in manufacture, &c., can be obtained from any agent. These points have not, as yet, received anything like the attention they deserve, and have, we believe, frequently led to very erroneous estimates in certain photometric experiments and reports of the value of illuminating agents, but especially those of a comparative nature in respect to gas.

As a low barometric pressure, and a high temperature, both diminish the bulk of the atmosphere in any place, it is evident that there will be a proportionally less amount of oxygen present in the atmosphere, than when a high pressure and low temperature prevail. This is familiarly known in our households by the bright burning of the fire in our grates in frosty weather, and the difficulty of keeping up a good bright fire in hot weather. In cold weather, each cubic foot of air contains a much larger proportion of oxygen than in hot; and, consequently, there is a less supply, bulk for bulk, in the air of oxygen, in the latter case, either for the burning of the illuminating agent, or of the common fire.

It is universally admitted, that the more abundant oxygen is present, the more rapidly combustion goes on; and hence its diminution lessens combustion, and, consequently, affects the amount of light afforded. For example, however dull a light be afforded by a candle burning in the open air, if it be plunged into a jar of pure oxygen, the flame becomes exceed-

ingly brilliant; indeed, phosphorus, that in the open air, during combustion, gives but a moderate light, will, in pure oxygen, give one that no eye can bear, and which vies with the sun in brilliancy.

From these facts and reasonings it will be evident, therefore, that variations in the pressure and temperature of the air will be attended with corresponding variations in the amount of light that any ordinary illuminating agent can afford; and, under certain circumstances, proper allowance should be made for such causes and effects. It is possible that some readers of this work may have large establishments lit with gas; and we need but appeal to their constant experience of the change in the amount of light attending on change of weather. The hints we have thrown out may, therefore, be very justly applied in extenuation of the sins of those much-abused companies who supply us with gas, at least to an extent justified by a consideration of the influences we have been discussing.

But it is not only that such variations arise from the alternations of atmospheric temperature and pressure: the hygrometric state of the atmosphere—that is, the amount of water as aqueous vapours it may contain—should also be taken into account.

It is familiar to all, that, on what is commonly called a "muggy" day, much discomfort is felt, especially in breathing. Many persons experience much difficulty in this respect, accompanied with great depression of spirits. This is chiefly due to the large amount of water held in solution in the atmosphere, and which is as prejudicial to health as it is to combustion. Perhaps here we may explain, that the process of breathing, and the arterialisation of the blood on the lungs, is precisely identical with the combustion of fuel in the furnace or grate, and that of gas, oil, or candles. When much aqueous vapour is contained in the air all these processes are impeded. Indeed, we have seen, on such a day as we are now speaking of, in a factory working at the utmost limits of its steam, that it was absolutely necessary to throw off a portion of the work from the engine because the stoker could not keep up the pressure; and this did not, nor could possibly, arise from any variation of the quality of the coals, but simply from the large amount of water-vapour in the air, and the diminished quantity of free oxygen.

It will follow, therefore, that when the air is loaded with moisture, not only do breathing and combustion in the furnace go on more slowly, but the light of any burning illuminating agent will also be affected. In each case, the duty to be performed is that of conversion of carbon and hydrogen into carbonic acid gas and water, respectively, by union with atmospheric oxygen; and as it is plain that variations in pressure, temperature, and moisture, affect the quantities of this, the brilliancy of our lights must correlatively be affected.

For similar reasons, but on a much more limited scale, an unventilated room, in which any illuminating agent is being burned, must, by the impurities of its atmosphere, much affect the brilliancy of light afforded. The large halls, theatres, churches, &c., of our towns frequently demonstrate this effect when crowded; and, on the smaller scale, the ball-room or large party evidences the same result. In the process of expiring the air from the lungs a great quantity of carbonic acid is given off, which is the result of the arterialisation of the blood by the air, through which the carbon of the venous blood is converted into carbonic acid. Again, every light in such a room adds to the vitiation of the air, and to the diminution of its power to support combustion "Dr. Frankland has made experiments to determine the relative amount of carbonic acid produced by the usual illuminating agents; and he states, that the following proportions of carbonic acid are produced, per hour, during the combustion of a sufficient quantity of each of the materials to get the light of twenty sperm candles, each burning at the rate of 120 grains per hour:—

Tallow	10·1	cubic feet.
Wax	8·3	,, ,,
Spermaceti	8·3	,, ,,
Sperm oil	6·4	,, ,,
Common London gas . .	5·0	,, ,,
Manchester gas	4·0	,, ,,
London cannel gas . . .	3·0	,, ,,
Hydrocarbon Boghead gas	2·6	,, ,,
Hydrocarbon Lesmahago .	2·3	,, ,,

"Now, if we bear in mind that each cubic foot of carbonic acid involves the destruction of nearly five cubic feet of air, and that a proportion of 5 per cent. of carbonic acid in the atmosphere is dangerous to animal life, we shall perceive that there is an enormous amount of atmospheric air vitiated and rendered irrespirable from this cause alone; but to this must also be added an almost equally large quantity of oxygen, which is consumed by the hydrogen of these illuminating agents, and which, in coal-gas, amounts, in many cases, to nearly 50 per cent. It will be manifest, therefore, that in obtaining artificial light by any of these means, we destroy a large quantity of atmospheric air."

From such facts we can at once perceive how the light of gas, oil, or candles must necessarily be diminished under the circumstances named; and this affords an additional reason, both as a matter of health and economy, that abundant ventilation should be kept in every place where life and light are intended to have a concomitant existence.

We have thus endeavoured to give a general outline of all the leading features that have to be regarded as generally affecting all systems or means of artificial illumination. Although so much has been, and much more requires to be said on the subject, the whole art is summed up in its objects by stating, that the best and most effective method of obtaining light by all ordinary means, is that in which a due proportion of carbon and hydrogen, in union, is presented to a proper proportion of oxygen to produce complete combustion, aided by such an amount of heat as shall be sufficient to carry out the preceding conditions. And, secondly, that,

exterior to these, it is absolutely necessary that complete ventilation shall be provided, which, whilst affording abundant access of external air, shall also carry off all products of combustion. On these two general principles, all successful attempts at rendering any mode of artificial illumination complete and perfect must depend. Personally connected with such matters for some years past, whilst watching the rapid growth of a good general system, yet we have frequently seen that this growth has been more apparent than real. An enormous number of inventions have been made, and numbers of patents taken out in every branch of the manufacture relating to the subject, whether of gas, oils, or candles. Still much remains to be done. The gas-supply is defective in purity, cheapness, and candle quality. The animal and vegetable oils are often crude and impure; and in respect to the candle manufacture, the experience of most of our readers will render any remark unnecessary. The most rapid progress that has been made in any department is that connected with paraffin, which, although a child of practical science not thirty years old, at least in respect to its commercial productions, has, in the form of oil, and the solid material for candles, far surpassed all similar illuminating agents.

Like each of the large manufactures, however, in which much capital is involved, every branch of that relating to light is constantly receiving vast improvement; and the pecuniary results of any really valuable invention are frequently enormous. Little, for instance, would the handsomely-dressed woman, passing men pumping tar from the street main, imagine that the colours of her garments, &c., have been dyed by its products; that the smelling-bottle and the pocket-handkerchief have been similarly filled with ammonia, and scented by coal-tar products. Yet such facts, surprising as they seem, are in their nature but typical of the great amount of gas products yet unutilised. There are scores as yet imperfectly known, and but partially studied; and we are by no means exaggerating when we state, that a few shiploads of good bituminous coal, contain materials that may be converted into products, the value of which would exceed that of the gold kept as a reserve in many large banks. Whenever man draws a properly-made-out cheque on nature, she is prompt to pay his demands, and leaves him to choose the amount of his draft on her.

THE MANUFACTURE, Etc., OF COAL-GAS.

The early history of the manufacture of coal-gas has been already detailed in the Introduction, and it now becomes our duty to enter into all necessary detail of its manufacture, purification, and distribution.

Although the above heading would seem to indicate that coal alone is the source of "gas" for illuminating purposes, we must, at the outset, state that such is not the case. All hydrocarbons are, more or less, capable of producing gas; but their value consists in the amount of illuminating effect they are capable of producing. Thus alcohol, or spirits of wine, is properly a hydrocarbon; but its combustion is attended with very little illuminating effect, because it is not capable of affording sufficient solid matter, as explained at p. 562, *ante*, to give a brilliancy of light. Ether, produced by distilling alcohol with sulphuric and other acids, is highly luminous when burnt; and if added to the acid solution acting on the zinc, as mentioned at p. 562, *ante*, affords a flame of great illuminating power.

All oils, again, by distillation at a heat approaching what is usually denominated red, afford a gas that can be adopted for illuminating purposes; and hence a large variety of materials may be used, from the waste of the grape-grower, or rather wine-maker, to the coal now universally the source of all gas supplied by public companies throughout the civilised world.

Coal is usually considered as a solid union of carbon and hydrogen, to which is added a small per-centage of oxygen, besides, in smaller proportions, sulphur, iron, arsenic, &c. The only valuable part in gas-making, is that which affords such compounds of hydrogen and carbon as produce gases which, during their combustion, give light. The oxygen, sulphur, arsenic, nitrogen, useless to the makers of coal-gas, either produce harmful results, or are sources of expense to *them*. Some of these products, however, are of great value; and their sale, as waste in the gas-house, gives rise to many important branches of manufacture; the tar, ammonia, &c., all being of great value in certain departments of trade, but especially in regard to the production of naphtha, nitrobenzole, aniline, &c., to all of which we shall subsequently allude in detail.

In regard to coal, there is no doubt that it is of vegetable origin. The specimens in our museums, which actually enable us to determine the species and genera of the plants of which the coal had been formed; careful chemical analysis; the secondary products of the dry distillation of coal; and the analogy, or rather identity, with those obtained from the distillation of parts of living plants—all confirm the opinion that coal is simply fossilised vegetable matter. Any of our readers may satisfactorily form a judgment of this theory by a simple inspection of the contents of his coal-cellar; for there is rarely an instance in which a few pounds of coal, carefully examined, will not at once prove that the plant alone, except by accidental admixture of mineral matter, has been the source of coal.

The chemical constitution of coal, however, enormously varies. An ordinary average good gas coal will contain about 80 to 85 per cent. of carbon; from 5 to 7 or 8 of hydrogen; the remaining per-centage consisting of oxygen, nitrogen, sulphur, arsenic, iron, earthy matter, or ash. The richest hydrocarbon coal that exists in this country is that at first obtained from Boghead, near Bathgate, at one time supposed to be confined to that locality, but now found to

extend in beds for twenty or thirty miles westward of that district in Scotland. Cannel coal, as obtained from Lesmahago, near Glasgow, Wigan, and other places in England and Scotland, and at times called "parrot," is exceedingly rich in hydrocarbons. In Scotland, near its localities, it is largely used for gas-making, as it is also in Manchester and neighbouring towns, because near all these places it can be readily procured. In the metropolis, however, its high price, from carriage and other causes, leads to only a limited adoption.

Usually, the metropolitan supply of gas coals is obtained from Newcastle, where excellent bituminous coal is shipped, gathered from numerous adjacent collieries, the term "Newcastle" being generic for a great variety of pits. With this the London gas companies mix a proportion of either Lancashire or Scotch cannel, by which the light-giving power of the coal is greatly increased.

The variation of the gas-giving power of coals (already stated to be very great) may be appreciated by the following estimate of some varieties, in which the proportion of volatile or light-giving matter, and that of the residual coke (an item of great importance as a source of profit in gas-making), is given.

Coal.	Hydrocarbons.	Coke.
Boghead	68·4	32
Staffordshire cannel .	50·0	50
Lesmahago	49·6	50
Stavely	40·9	59
Silkstone	38·0	62
Wigan	37·0	63
Elsecar	37·0	63
Newcastle (average) .	37·0	63
South Wales	23·0	77

The preceding list is but a selection from the great varieties of coal found in this country that may be employed in gas-making. But, apart from the amount of production of hydrocarbons of any specified kind, many other matters have to be considered. Thus, if too much ash be present, even in a rich coal, that would be a fatal objection to its use, because the labour of casting in and removing useless material from the gas retorts would greatly increase the expense. Boghead coal, for example, affords 22 per cent. of ash, or earthy matter, which has no useful application of any kind. Lesmahago gives only about 9 per cent. of ash; Wigan, 3 per cent.; Elsecar, not much over 1 per cent.; and Newcastle coals vary from 3 to 6 per cent. of ash.

Again, if the proportion of carbon in any coal exceeds a certain amount, it becomes valueless to the gas-maker, for he then converts his retorts, like the Earl of Dundonald's first attempts, into mere apparatus for distilling coal for the sake of obtaining coke and tar.

Practically, in the manufacture of gas, such coal is used that, whilst parting with all its hydrocarbons as illuminating agents, yields from 60 to 70 per cent. of coke—a result obtained, on the average, from good Newcastle coals. The material of this kind is easy of management; yields a good saleable coke; and, generally, may be depended on for uniformity of production—a matter of great importance in all large manufactures; because any excess in variation above or below any generally received standard of quality, although beneficial in the one case, introduces several elements that disturb the regularity of operation in the works, and calls for an interference in them that frequently neutralises all apparently extra or possible profit.

The following judicious remarks by Mr. Colburn, in his *Gas-works of London*, may here be quoted:—"At many of these works, two qualities of gas are made—ordinary gas and cannel gas, the latter having two-thirds more illuminating power than the former; the usual price of ordinary gas being 4*s.* 6*d.* (occasionally 4*s.*) per 1,000 cubic feet, while cannel gas is sold at about 6*s.* The Western Gas Company make only cannel gas. For ordinary gas, the coal used comes from the neighbourhood of Newcastle. A good house coal is not, as a rule, the best gas coal, as the latter might be too smoky and 'crusty.' Hence it is that the coal from Pelton, Haswell, Lambton's, Leverson's, and Pelaw pits, being especially rich in hydrogen, and therefore preferable for gas-making, ranks, in price, considerably below that of Wallsend. Thus, North Pelton gas coal has been lately quoted as low as 12*s.*; and, perhaps, 14*s.* is a fair average price for gas coals in the Pool, where the Surrey Consumers' Company unship them at their own doors. Cannel gas is either made from Lancashire, Scotch, or Welsh cannel coal; or it is made by mixing the gas from Newcastle coal with that made from Boghead coal. Some of the Newcastle coals contain a certain proportion of cannel in combination. From the Leverson coal, for instance, more or less cannel may be picked out. At the present, for making cannel gas up to the parliamentary requirement, the proportion of Boghead to Newcastle coal is about 3 to 7·30 per cent. of the whole amount of coal carbonised of the former, and 70 per cent. of the latter variety; the different kinds of coal being carbonised in separate retorts, so set that the gases may meet and intermingle in the hydraulic main over the retorts."

From the preceding quotation from a work written in 1864-'65, we have omitted the following statement in respect to Boghead coal. It is—"The latter now brings 56*s.* per ton; and its price is likely to rise to one at which gas companies can no longer afford to use it." Shortly after these remarks were penned by Mr. Colburn, we visited (in December, 1864) the then sole locality where Boghead coal was obtained, which was in immediate adjacency to the paraffin works of Mr. Young, who employed this coal exclusively in the manufacture of paraffin. But about the same period in the following year (1865), and at the commencement of 1866, we traversed the whole district from Bathgate to Airdrie; and instead of finding only the sole "field" that previously existed for the Boghead coal, the entire distance between the two towns

just mentioned—a distance of several miles—was dotted, here and there, with paraffin factories; all drawing their resources of coal from fresh-discovered beds, the existence of which had not been previously imagined; and since that date (1866), the area of the bed or field has been found to extend much further—so much so, indeed, as to have reduced the manufacture of paraffin, two or three years ago almost as profitable as coining, to one requiring the greatest care to render even a moderate profit.

These facts, &c., have been quoted and stated, not so much for the sake of the information they convey, as for the purpose of showing how speedily that which might for the moment be accepted as an exact statement of the truth, becomes almost suddenly falsified by fresh discoveries. Indeed, it is a great discouragement, and the cause of anxiety of all who attempt to produce an account of what exists in respect to science and its applications, to know that what may be true in one year, or even one month, may become at times seriously modified, and even reversed in the following one. A few years ago, for example, the shores of the Dead Sea, Baikal, Trinidad, and a few other places, were described as the only sources of petroleum. But since then, the discovery of the "wells" in North America, and even in our own country, has made that article almost as common or abundant as water.

Before entering on a description of the details of the gas manufacture, we may properly notice the first and chief products of the distillation of vegetable organic matter, as found in wood, peat, coals, &c., &c.

On the first application of a heat of about 212° to any of these, the aqueous or watery portion commences to distil over. Succeeding to this, and at the temperature of charring (possibly below it), inorganic acids, as the pyroligneous, &c., some kinds of spirit or alcoholic-like fluids, are given off. As the temperature increases, a variety of interesting chemical changes occur, and a still greater variety of oils, &c., are given off, together with carbonic acid and oxide. Ammonia and certain cyanogen compounds are also afforded at this and the preceding stage of operations. At a heat just below redness, cannel and Boghead coal give off paraffin, the separation, distillation, and purification of which will become the subject of a separate notice. All the preceding are condensed or condensible into fluids, soluble or insoluble in water; and in the manufacture of gas, they are chiefly collected in what is called the hydraulic main, already alluded to, but more particularly to be described when we enter into the examination of the apparatus of general use in gas-houses. It is sufficient here to state, for the present, that the hydraulic main is a horizontal pipe, into which the ends of other pipes proceeding from the closed extremity of each retort dip or end; delivering their gaseous and vaporous contents into this main, where they either remain for removal as liquids, or pass on to the purifiers and gas-holders as gases.

As the heat of the vessel—for example, the retort of the gas-house—increases, the gaseous hydrocarbons are given off; that is, such combinations of hydrogen and carbon, besides hydrogen alone, that go to produce the coal-gas used for illuminating purposes. There are chiefly two of these—namely, *light carburetted hydrogen* (also called *marsh gas*, a bihydride of carbon, in which two atoms or equivalents of hydrogen are united with one of carbon), and *olefiant gas*, in which two atoms of carbon are united with two of hydrogen. It is to this latter gas that the illuminating power of coal-gas is chiefly due.

The hydrogen itself has no illuminating power, as already explained at p. 562, *ante*, when we spoke of the nature of flame. Its presence in coal-gas, therefore, can only be ascribed of value because it is highly inflammable, and during combustion produces great heat. Being the lightest body we know of in nature, it is but reasonable to expect, that as, during combustion with oxygen, it becomes water, and in that state occupies only about $\frac{1}{12000}$th of its bulk as a gas, that it should give out a great amount of latent heat during its conversion from the gaseous to the fluid condition.

But there are other hydrocarbons, in some number, that are held in solution by the preceding, and, to a certain extent, affect or improve their illuminating power. These we shall subsequently notice by themselves, for their proportion and presence in ordinary coal is rather accidental than essential.

Carbonic acid is absolutely valueless, and, indeed, exceedingly harmful in gas; and by lime, or other means, it is readily separable from it. Carbonic oxide, however, is inflammable, and generally exists in the gas supplied by most works. It burns with a blue flame, of which it is the cause, as seen occasionally in the common house-fire, especially when cinders are abundant; and also it produces that flickering blue flame seen on the top exterior of burning brick-kilns. By combustion, carbonic oxide is converted into carbonic acid; and hence becomes an additional source of that gas towards vitiating the air of apartments, referred to, and in part explained, at p. 570, *ante*.

Taking coal-gas as supplied from the street mains, there are certain other products that generally escape all attempt at purification within the works; and, therefore, for our present purpose, may be considered practically as part constituents of ordinary coal-gas. It will be here noticed that we are now merely tracing the gaseous products from the coal to the houses supplied by the works, and entirely omit all notice of the valuable fluids there retained.

A most common constituent of coal-gas is ammonia, that pungent volatile alkali familiarly known in the smelling-salts of commerce; also as produced by burning animal matter, the decomposition of urine, and from other sources. It is a compound of nitrogen and hydrogen. The former element, nitrogen, is found in exceedingly variable proportions in coal, some containing none, and others a large quantity, comparatively speaking. In coal, as in animal

matter, ammonia does not exist naturally, but is produced by heat uniting its two elements.

Ammonia is an exceedingly objectionable constituent to coal-gas, for many reasons. In the first place, its escape from the works is a dead loss to the company, for the ammoniacal liquor is a source of considerable profit. Secondly, it diminishes the illuminating power of the gas, and, consequently, reduces its candle value to the consumer; and if this should run pretty close to the limit, in the manufacture by the company, they must either incur sundry penalties for breach of the act of parliament regulating the sale of gas, or make up the deficiency of illuminating power by means already suggested, but that cannot, at present, be explained in full detail. Lastly, it has a most injurious effect on all brass connections, which it rapidly destroys, at least as regards their accuracy of fitting, by acting on the copper. It consequently causes leakage of the gas, and an unpleasant smell, besides the possibility of inducing explosion when the leakage becomes extensive. It has been lately discovered, that ammonia thus conveyed in the gas, forms an explosive compound of ammonia and copper, which, in certain instances, has been productive of personal injury to those unacquainted with its existence.

For these reasons, it is evident that the detection of ammonia, as present in gas, is a matter of much importance, especially to the consumer; and the following methods can be followed with a certainty of success, and without any knowledge of chemical science.

The operative chemists sell what is called "turmeric paper," the common detector of alkalies in the laboratory; but which, however, may easily be made as follows :—Boil an ounce of powdered turmeric root in half a pint of water; and, after the powder settles down, dip into the clear infusion narrow slips of white blotting-paper. These should be dried and kept in a box, so as to prevent access of air as much as possible till required for use.

The slips so made have a yellow colour. Before testing the gas supplied from the main, the paper should be held for a few seconds over the steam of boiling water, to impart to it a slight degree of moisture. The slip is then to be placed over the gas-burner, and the tap turned on, so as to allow a stream of *unlit* gas to flow on to the paper. If ammonia be present it will be instantly detected by turning the paper to a reddish-brown colour; which, however, will gradually vanish on the paper being removed from the gas, because the alkali is very volatile.

Another and ready mode of detecting ammonia in gas, is that of holding a glass rod or piece of wood, previously dipped into strong hydrochloric acid (also called, in commerce, vitriol, spirits of salts, and muriatic acid), over the issuing jet of gas, as in the last method. If ammonia be present in the gas, abundant heavy white fumes will be given off, very different from those of the acid, and consisting of sal-ammoniac.

Another compound of gas, very generally present, and exceedingly injurious to the property of the consumer, is *sulphuretted hydrogen;* or, as it is now more commonly termed in science, *hydrosulphuric acid.* It is produced, during the distillation, by the union of an equivalent each of hydrogen and sulphur, the latter being frequently present in coal in the form of iron pyrites—that yellow, gold-looking-like substance, that may be noticed in many coals.

This gas is familiarly known in our houses as causing the smell of drains; it is also produced in decomposing soap-water, rotten eggs, decomposing "vegetables," and generally during the putrefaction of animal and vegetable substances. It is this gas which, whether arising from drains, escaping gas, or other causes, turns the white paint of an apartment into a dingy brown or even black hue. But the results of its combustion are still more serious; for during that process it is converted into sulphuric acid or oil of vitriol, which, collecting on curtains, bed-furniture, books, metal surfaces, &c., in an apartment. gradually acts on them, and destroys them. This effect was first noticed, on the large scale, in the library of the Athenæum Club, London; and Faraday, being consulted as to the cause, pointed out that it was due to the formation of sulphuric acid, from causes just specified.

The detection of this gas is easy, even to a person unacquainted with scientific manipulation; and may be effected as follows :—

A little acetate or sugar of lead, which may be procured of any chemist and druggist, is to be dissolved in water, soft water being preferred. Into this a slip of white blotting-paper is to be dipped, and, on being completely moistened, it should be drained until no more liquid drops from its edges. The slip is then to be held over the issuing gas stream as previously directed, when, if any sulphuretted hydrogen be present, the lead solution in the paper will acquire a black hue, owing to the union of the sulphur of the gas with the lead of the acetate. This is an exceedingly delicate test, and may obviously be used for the purpose of detecting the presence of sulphuretted hydrogen in drains, &c.

Another source of the production of sulphuric acid, and one exceedingly difficult of detection, is due to the presence of a compound of sulphur and carbon, called the bisulphide of carbon, that is generally present in gas, and which has an exceedingly offensive odour, resembling that of rotten greens. So far as the smell is concerned, we have frequently detected it in Glasgow and Edinburgh gas; which, however, are remarkably free from ammonia. It is useless to give any directions for attempting to discover its presence by tests, as by any method of accuracy much experience in manipulation would be required.

Another ordinary accompaniment of gas, as supplied to the consumer, is the vapour of water, which, although apparently trifling in itself, often causes great annoyance and inconvenience. It is through the gradual condensation of this in the supply-pipes, that the occasional irregular, flickering, or "bumping" light of the gas-lamp is occasioned. By a little contrivance on the part of the gas-fitter, this source of inconvenience may be greatly obviated.

This consists in so fixing the pipes that any condensed water may gradually flow back to the meter, where it can do no harm. Of course, in bends this cannot be done; but a small tap placed at the lowest part of such bends, would afford constant facility for drawing off any water that may collect in such portions of the pipe.

The offensive smell of gas—which is really a boon rather than an objection, for it warns of all danger arising from an escape—is due to the presence of a variety of sulphur compounds (yet but little understood) with ammonia, and, perhaps, tarry matter. The smell of gas greatly varies, according to the character of coal used, the state of the purifiers at the gas-works, and from other causes too numerous to mention. The Glasgow gas has a smell somewhat resembling phosphorus, and partly of an onion-like flavour also, as just previously mentioned of the bisulphide of carbon: but that gas is quite free from pungency, owing to the absence of ammonia. London gas, on the contrary, as a rule, always smells of the latter constituent; and is consequently pungent, besides being constantly very offensive.

So far in respect to the general and chemical qualities of the gas ordinarily supplied in this kingdom. In physical properties coal-gas resembles all others. It is elastic, and consequently is subject to all the influence of pressure, compressibility, &c. In its passage through the mains, it is forced by a varying pressure, originated in the gas-holder of the works, but under full control, by means of governors or regulators, that will be hereafter described. Like all fluids it suffers friction, and consequently hindrance, in its passage from the works to the consumer, not only in the small pipes used by the latter, but also in the large mains of the street arrangements. It has already been shown, at p. 570, *ante*, that it is influenced in burning by variations in the pressure, temperature, and moisture of the external air.

The density of coal-gas, of the London supply, is from ·400 to ·412, air being taken as the standard of unity, or 1·00: it hence has nearly six times the density of pure hydrogen, which is about 0·069; air = 1·000.

But it is a great error to suppose, that because coal-gas is lighter than air that it will always ascend to the top of a room, and escape by any opening, unless of large size, at that portion of an apartment. On the contrary, there is with all gases a power called diffusion, by virtue of which a light one will descend to mix with a heavy one. Thus, if a glass tube, two or more feet long, be divided in the middle by a diaphragm of plaster of Paris (which is slightly porous), and the lower end of the tube be filled with carbonic acid gas, which has $1\frac{1}{2}$ times the specific gravity of air, whilst the upper portion of the tube be filled with hydrogen, which is fourteen times lighter, or has only one-fourteenth the weight of the same bulk of air (both ends of the tube being closed air-tight), after a short time the heavy carbonic acid gas will find its way up into the hydrogen, and, *vice versâ*, the hydrogen will descend into the carbonic acid gas, owing to the mutual diffusibility of each and both.

Precisely the same thing will occur in any close place into which gas escapes, as an ordinary room. Although this may only take place for a short period of time, still the air, if at rest, will be gradually mixed by this diffusion with the gas, and all parts of the room become so charged, that, on a light being introduced, an explosion of air and gas would instantly ensue. For similar reasons, it is impossible, under the present limited system, to ventilate coal mines sufficiently to prevent the same danger occurring. The frequent and awful accidents that happen therein, are only too sad a proof of the truth of this assertion; and are illustrated by the immense loss of human life that so often results in collieries from such causes. (See Chapter I., where the subject is fully dealt with.)

From the preceding facts, it will be seen that much scientific knowledge, in respect to chemistry and other branches of science, is involved in the manufacture of gas. It is one, in fact, that must necessarily be conducted on scientific principles; because all the results that tend to profit are dependent on the extent to which such principles are used or followed. It has been frequently supposed that a gas-works must necessarily be a money-paying affair; and so, practically, they are, because, with careful management, leaving even a small margin of profit per 1,000 cubic feet, still the enormous consumption pays in the end.

As we shall subsequently notice, much gas, in its transit from the works to the consumer, is lost by leakage of pipes. Competent authorities have estimated this at one-sixth of the total production. The continually-occurring smell of gas in our streets and roadways is a familiar evidence of this fact. The varying price of coals, the distance from the colliery, the cost of transit, unloading and delivery at the works; the varying price of iron, bricks, lime, and various other materials; the varying sale of the coke and waste products, tar, ammonia, &c., whether in respect to quality or price; with a great many other matters that cannot here be particularised, tend to render the entire operations such as require much careful calculation and management. On the other hand, the risk of bad debts and other losses may be but small, as particular powers lie in the hands of the directors. Then, again, gas-supplying is generally a monopoly, not necessarily by act of parliament, but because the extent and general nature of the works are such, that whilst great profits may be gathered in certain instances, new works especially, if competing with those that are old-established, run, at first, great risk of remuneration to the shareholders. To those who are acquainted with the back-scenes of the gas manufacture, it is no secret that a little extra firing may raise the production of gas, from certain classes of coals, at least 20 per cent. Thus a good coal, yielding nine to ten thousand cubic feet per ton, may be run up to eleven or twelve thousand.

We were privately informed, by the super-

intendent of certain gas-works in a part of this kingdom highly favoured in respect to adjacency of pits producing the best quality of coal for gas purposes, that this was just the course he took—running down the candle value of the gas he supplied 15 per cent., because an agitation was made for a reduction in price of 10 per cent. It is barely a question whether a comparatively high-priced but excellent gas is, after all, dearer than a low-priced and low-candled gas; and, perhaps, eventually, this view of gas-cheapening may become more universally adopted than it is at the present day.

In respect to the present cost of gas, or rather, in 1865-'66, Mr. Colburn, the engineer, thus expresses his views:—"Taking the gas actually paid for at 4*s.* 6*d.* per thousand cubic feet, its cost is 2*s.* 4*d.* for coal, and 1*s.* 10*d.* for manufacture and management; making 4*s.* 2*d.* in all. But of this, rather more than 1*s.* 1*d.* is returned in residual products. Thus the net cost may be taken at 3*s.* 1*d.* Then, for every ton of coal carbonised yearly in the gas-works of London, about £6 10*s.* of fixed capital is invested; and at the now usual rate of 10 per cent. dividend, there is thus a charge of 13*s.* per ton of coal as profits. This estimate of capital includes that borrowed, however; but, taking this as bearing interest at 5 per cent., the charge for interest and profits is still 11*s.* 6*d.* per ton of coal carbonised, or 1*s.* 7½*d.* per thousand feet of gas for which payment is actually received.

"The price of coals can hardly be expected to diminish; and, therefore, after all the agitation created by a certain class, the only hope of cheaper gas lies in one or all of three contingencies—First, in diminished leakage; second, in making a greater profit upon the residual products; and third, in a diminished profit upon the capital employed. It is quite possible that all the ordinary gas burnt in the metropolis may yet be sold at 4*s.*; but any diminution in price must be the result of time."

This work is, of course, not the place for any discussion of such subjects as are involved in the preceding quotation, which has been adduced to show the generally existing opinion of those really engaged in the manufacture of gas, and not speculating on what might be done. We shall, therefore, leave the subject, more especially as, at a comparatively recent date, the government have taken up the gas question, and passed a bill through Parliament relating to the existing companies, and regulating future arrangements for the supply of gas to the metropolis. In certain cities of this empire, the manufacture is resident in the corporation, as is also the water-supply; and, doubtless, before long the entire subject will be sufficiently ventilated to enable justice to be meted out alike to the consumers and makers, whether the latter be private companies, municipal incorporated bodies, or some form of board of works.

There does not seem any probability that other sources than coal can be employed economically to supply gas on the large scale, and so, by economising its manufacture, to diminish its cost. As we shall see in future pages, many other materials from the vegetable kingdom, but especially oils, have been tried; but they have invariably proved more expensive than coal itself; and although frequently at first promising success, have been found of no value. One hope or chance to which Mr. Colburn alludes—the diminution of leakage—may probably be realised, owing to the great improvements that have been effected, of late years, in casting pipes. The pressure of gas in the mains is, unlike that of water, but trifling; but a little leak is a dangerous thing; for, owing to the tenuity of coal-gas, it rapidly escapes even under slight pressure. It is not necessary that a hole should exist in a pipe to cause great loss. Even a small crack, almost invisible to the eye, answers perfectly well for occasioning that cause of loss; and there is no doubt but that an immense amount of gas is annually lost in the metropolis through such causes, and which is not discovered until, by some accident, the neighbouring earth is removed, and the previously latent evil exhibited to its full extent. Most of our readers will have noticed, that frequently, when gas-pipes are laid bare, the adjacent earth is perfectly black. This generally arises from an escape of gas, which results in the deposition of tarry matter on the soil; and is an evidence of the existence of some fault in the pipes. It is not improbable that a better material may be eventually adopted than iron, which being generally caulked with lead at the joints, must constantly be forming voltaic currents, by which the iron, as the most positive metal, is rapidly corroded. Under ordinary circumstances, no agent acts more rapidly on iron than ammonia; and, as we have previously shown, it is constantly present in coal-gas, as supplied, at all events, in the metropolis.

We have now noticed most matters of interest that can be conveniently inquired into before entering into a detailed description of the processes, plant, &c., of the gas-house. Generally, the methods adopted in London will form the basis of the succeeding observations, and statements of facts; but such modifications as may arise from local circumstances will not be lost sight of. These chiefly arise from variations in the quality, especially as evidenced in the districts where cannel gas is made from coal obtained at adjacent pits, as in Manchester, Wigan, and neighbouring towns, Glasgow and Edinburgh, and the south of Scotland generally. As in most manufactures, so in gas-making, it does not occur that we can take full advantage of the facts afforded by accurate chemical analysis; but in all cases they give an invaluable guide, which the provident and economical manufacturer follows as closely as circumstances permit.

We have only as yet named some, but have scarcely described any, of the valuable products that the results of the dry distillation of coal afford. These will be more conveniently noticed after the practical manufacture of coal-gas has been described. Their utilisation forms an epoch in the history of Applied Chemistry:

and in connection with this, we must add, that chiefly to Faraday are we indebted for the great improvements that have thus arisen in various operations of dyeing, calico-printing, the manufacture of benzole, &c., &c. Years ago, his discoveries laid the foundation of our present success and profit from such sources; and he has fortunately lived to see some of the enormous social, commercial, and national benefits which the application and extension of his abstract researches resulted in.

The Gas-house, its Plant, Operations, Etc.

Whilst the entire plant, operations, &c., of the gas-house may, in principle, be briefly described as, first, the retort for distillation of the coal; secondly, the purifying process; and, lastly, the storing of gas in the gas-holders or gasometers—the intermediate matters of these three primary points are numerous, and the subjects of considerable detail. In fact, as in all other extensive manufactures, whilst the principles are extremely simple, the details become frequently very complicated.

The entire business of gas-making, as regards its results, is really comprised in the production, at least so far as the metropolis is concerned in the manufacture, of gas and coke; the residual products, as we have seen at p. 572, *ante*, being a considerable item in respect to the profits of gas-making. Thus, on entering any large gas-works, it is usual to notice a double set of offices—one devoted to all matters pertaining to the sale of gas, and the other to those connected with the sale of coke. In respect to the gas-tar, ammonia liquor, spent lime, &c., these generally become the subject of special contracts entered into by persons who are engaged to carry them away for utilisation, in a manner to be hereafter described.

The first, and perhaps the most important part of gas-works is the retort-house, which is, practically, the initiative of the whole process of gas-making; because here the dry distillation of coal for producing gas is carried on. Generally the retort-house is a long building, one side of which is occupied by the furnaces enclosing the retorts; the centre is devoted to the reception of the coke that is withdrawn from the retorts after all the gas has been removed from the coal; and at the other or outer side is the coal used to charge the retorts in the manufacture of gas. The coal is wheeled by barrows to the retort-house, and heaped up in masses. The enormous consumption of coal requires that, in most cases, large stores should be kept; and careful precaution is needful to prevent spontaneous ignition, from the readily inflammable character, often spontaneous, of some kinds of rich bituminous coal, or that containing a certain quantity of iron pyrites.

Formerly the retorts were exclusively made of cast-iron. Usually they were about seven feet in length, closed at one end, and open at the other; the latter being closed, during the manufacture of the gas, by a movable lid, luted on by clay, and affixed to the retort by clamps and bolts. A section of such a retort would present the appearance of the capital letter D; but placed horizontally, thus , instead of vertically. Such retorts are charged by throwing in coal at the open end, on removal of the lid and the coke.

But, for some time past, fire-clay retorts, made in one piece, open at both ends, and about twenty feet long, have been preferred. These are made of a circular, elliptical, or  shape. The sides are about $3\frac{1}{2}$ inches in thickness, and the internal diameter varies from 15 to 26 or 30 inches. The retorts, placed horizontally, in numbers varying from five to fourteen, in a kind of oven of fire-brick, heated by either a single or double furnace at each end, form what is technically termed a "bench." The number of these congregated together in a retort-house greatly varies, and depends on the extent of operations carried on. The following interesting particulars are extracted from Mr. Zerah Colburn's work on the *Gas-works of London* published a few years ago :—

"At the Pancras station of the Imperial Company (now extinct) there are nearly 600 retorts, 20 feet long, or 1,200 'mouth-pieces' [that is, openings at each end of the retort], the retorts being worked from both ends. These are generally set ten on a bench; although on some benches there are but six retorts. At the Hackney Road station of the same company there are 386 retorts, each 19 feet 6 inches long; a large number being set ten in a bench. At the Fulham station of the same company, there are 380 long retorts, 240 of which are set six in a bench; while 140 more are set ten in a bench. It is to be borne in mind that six is the number now adopted in setting new retorts.

"At the Horseferry Road station of the Chartered gas-works, there are equal to 400 long  retorts, or 800 mouth-pieces. Some are set eleven in a bench, although a smaller number appears to be preferred. At the Goswell Street works, some of the retorts are but 9 feet long, and worked only from one end. There are 545 mouth-pieces, equal to $272\frac{1}{2}$ full-length retorts. All are set five in a bench. At the Curtain Road works, only single-end retorts, 9 feet long, are used; and of these there are 155, equal to $77\frac{1}{2}$ retorts 18 feet long.

"The Vauxhall station of the Phœnix Company has 357 retorts, 20 feet long, mostly cylindrical, and all set seven in a bench. At Bankside there are 140 retorts, of the same length and shape, and set seven in a bench. At Greenwich a smaller number is used.

"The City of London gas-works, Dorset Street, have single and double retorts, mostly cylindrical, equal to 920 of the former, or 460 of the latter. There are a few single retorts. A small number also of retorts are of iron. The usual number placed in a bench is seven, although some are set five together. (These works have ceased to exist.)

"The London gas-works, Vauxhall, have about 250 retorts, mostly cylindrical, 16 inches in

diameter, and about 19 feet long. They are usually set nine in a bench, with one fire-grate at each end of each bench; although a number are set twelve in a bench, with two fire-grates at each end.

"The Equitable gas-works have twenty-nine benches of 19 feet 6 inches retorts, some with seven, and others with nine in a bench. (This Company is now extinct.)

"The Commercial gas-works have 270 long retorts, mostly set seven in a bench.

"The Ratcliffe gas-works have 195 long retorts, set seven in a bench.

"The South Metropolitan have 195 long  retorts, all but one bench containing seven in a bench.

"The Great Central Gas Consumers' works have 279 long retorts, eleven being the number generally set in a bench. The benches are very high, and the retort-house is divided into two storeys, seven retorts opening upon the upper stage, and four below, where the fire is made. The retorts are all clay. Originally Mr. Croll, at that time engineer, and afterwards the contractor for carrying on the works, made the fires on a level with the upper stage, where the heat first acted upon six clay retorts, afterwards descending and acting upon seven iron retorts below. (Company now extinct.)

"The Surrey Gas Consumers' works, until lately worked by Mr. Croll, have sixteen benches of long elliptical retorts, the retort-house being divided into two storeys. The fires are made upon the upper stage, where the fire from each grate acts first upon six clay retorts, 15 inches in diameter, afterwards descending to eight cast-iron retorts below; there being fourteen in a bench.

"At the Western gas-works there are 65  and 102 circular retorts, 22 feet long, set generally seven in a bench. We may here notice a peculiarity of the retort-house at these works. As originally designed by Mr. G. H. Palmer, it is a twelve-sided building, forming a dodecagon in plan. The retorts were originally placed around the building, against the sides. When long retorts afterwards became used, all the benches were taken down, and others set up, so as to form ranges radiating from the centre of the house outwards.

"At the Independent gas-works there are 301 mouth-pieces; the retorts, mostly of full length, being set seven in a bench. (Now extinct.)

"At the various works of the Chartered Gas Company, and at the South Metropolitan works, the retorts are built, on the spot, of fire-bricks. At all the other works, we believe that retorts moulded in fire-clay are exclusively used, with the exception only of the small number of the iron retorts already mentioned. Mr. Grafton, of Cambridge, patented the clay retort in 1820, and it soon came into extensive use in Scotland; so soon, indeed, that Mr. J. B. Neilson, the patentee of the hot blast for iron-smelting, and who was originally engineer to the Glasgow gas-works, has had the credit of the first application of clay to gas retorts. It was many years, however, before clay retorts came into extensive use in England. An iron retort, 20 feet long, and of medium diameter, weighs about two tons; costs about £12; and is worn out after having distilled about 1,500,000 cubic feet of gas (750,000 feet if the retort be a single one, 9 feet or 10 feet long), which is equal to an average year's work. A clay retort of the same size, costing 6*s.* per foot, or £6 in all, will generally be in good condition after three years' use; and some are said to have been worked for from five to eight years. Rather more fuel is required for heating clay retorts than is necessary with iron [because of the non-conducting power of the material of the former]; but the clay can be worked at a higher heat, which gas engineers generally consider to be an advantage. In America, where the cheapest gas (made at Pittsburgh, from coal dug almost at the doors of the works) costs 6*s.* 3*d.* per 1,000 cubic feet, the price in New York being 10*s.* 6*d.*, and in Philadelphia, 9*s.* 6*d.* per 1,000 feet, clay retorts are only beginning to be used, notwithstanding, too, that the old single-end iron retorts have sold there for £14 per ton—prices that ruled before the war." *

In respect to the materials used in making the retorts, the best fire-clay is employed, either for the solid-made retorts, or those made up of bricks. The Welsh (Dinas), Stourbridge, and Newcastle clays are mostly preferred for such purposes; but some have been imported from Belgium, and other places. "The fire-clay retorts are moulded about three inches thick, and generally in lengths of from four to six feet. The lengths intended to form the outer ends of the retort are thickened to rather more than four inches, and holes are formed in the clay to receive five or six bolts for holding on the mouth-pieces, which are short extensions of the retort, and always made of cast-iron. To fasten the several lengths of the retort end to end together, so as to form a single retort, is easily accomplished, by introducing at the joints, and in a plastic state, a little fire-clay, as nearly as possible of the same quality as that of which the retort itself is made. With this clay in the joints, precisely as mortar is enclosed in ordinary bricks, the retort is set or got into place on the bench, where a high heat is applied, and the separate lengths burnt into one continuous tube, complete, and ready for use. Of course, all the retorts in a bench, whether there be five or seven, or a dozen, or more, are thus burnt together at the same time. It is usual to make a narrow, shallow groove in each abutting end of the several lengths, the fire-clay for joining having thus a better hold while soft. Many gas engineers, however, now order retorts without this groove, the abutting ends being left smooth as the other surfaces of the retort."

The setting of these retorts is a matter of considerable importance, although, unlike iron retorts, they do not expand constantly on being heated; indeed, on the contrary, all clay, more

* In a subsequent page, some recently erected gas-works will be described.

or less, contracts; but the mode of constructing these retorts is such, that any alteration of their length, in use in the gas-house, is trifling. Generally, in London, they are built into brick partitions, each of which is about fifteen inches from centre to centre, and serve as a support to the retort and direction of the flame of the furnace. Much care, however, is needed in heating and cooling clay retorts, because, having little tenacity compared with that of metal, they are far more readily fractured by excess or sudden decrement of temperature. Retorts built up of fire-clay bricks have not generally come into use; for, of course, the greater number of joints renders their stability less certain, and increases the possibility of leakage; besides which, must be taken into account the necessarily unequal quality of the material of which they are constructed.

As already noticed, the set or bench of retorts is practically enclosed in a kind of oven, at each end of which the furnace is placed. The heat is directed from the crown of the fire-place to the retorts, where it circulates between the brick partitions, already described as forming the support of the retorts in each nest or bench. The heat is preferably applied to the sides and tops of the retorts by a kind of reverberatory action, produced by the general internal construction of the oven and fire-place; indeed, the heated flame, which has an exceedingly high temperature, is conducted over and at the sides of the retorts, generally escaping by descent into the chimney-stalk, which has also to bear an enormous heat, and, therefore, in many cases, is constructed of fire instead of ordinary bricks; and as the wear and tear of all parts of the furnace, oven, retorts, &c., is very great, owing to the intense heat to which they are subjected, it is impossible to exercise too great care in selecting the most refractory material for constructing them. This, whilst only referring to the use of clay retorts, is especially to be noticed when iron retorts are used; for they, of course, greatly expand when heated, and contract when cooled; consequently much affecting the stability of the whole arrangement, and necessitating the use of ties and bonds in all parts where such an influence could be prejudicially exerted.

Whatever retorts are used, the open ends are necessarily closed with movable pieces, already described as mouth-pieces, and the opening of which is required to charge and empty the retort. These mouth-pieces are made of cast-iron, and from them the pipes ascend through which the gas passes to the hydraulic main. They are fastened on to the end of the retorts by bolts, and between the face of the ends of the retort and the flanges of the mouth-piece, iron cement is spread, to make the junction gas or air-tight. Holes are left in the retorts and mouth-pieces, through which the bolts can be passed. In fire-brick retorts, modifications of this method are necessary; and they have received various forms suitable to special circumstances.

Having described the construction of the furnaces, oven, setting of the retorts, &c., we must next notice the method of charging them.

If this is done by hand, the coal being already heaped up near the benches, a scoop of sheet-iron is employed, furnished at one end with a handle, by which the scoop may be inverted in the retort so as to turn out the coal into it. This operation is performed at each end of the long retort—say twenty feet, as already described; and, on the retort being charged, both ends are closed by covering with the lid that encloses the mouth-piece, which is thus made air-tight, except where the gas escapes by the ascension-pipe to the hydraulic main, on its road to the gas-holder. The charge of each long retort varies from about 2 cwt. to 3 cwt.; and they are filled and emptied generally every six hours. On an average, each large working retort will carbonise about a ton to a ton and a quarter of coals in twenty-four hours; but, of course, a variety of circumstances affect this amount of work.

It need scarcely be stated, that the labour of charging, and, still worse, that of emptying the retorts, because of the heat of the coke in the latter, is very great. The latter operation is termed "drawing," and severely taxes the strength of the men, who will frequently supply the loss of moisture in the body by perspiration with draughts of liquid, equal, in quantity, to about two gallons daily.

An ingenious machine has been invented that replaces human labour in such trying duties; and for a description of it, we are indebted, by the kind permission of the Editors, to the columns of *Engineering*, so ably conducted by those gentlemen. Numerous inventions of a similar kind have been brought out, at different times, with varying success.

"There are few kinds of labour more severe than that of drawing and charging gas retorts as at present conducted. According to the system now generally adopted, the working of the retorts is performed by men working in gangs of five each, three of the men composing each gang being actually engaged in the charging and drawing, and the other two being employed in attending to the fires and in wheeling the coals. In the London gas-works, the number of mouth-pieces allotted to each gang varies from forty-two to fifty-six, and the men work twelve-hour shifts, the retorts having generally to be drawn and charged twice during that time. To reduce the large amount of manual labour necessary under this system of working, and to render that which is required less severe, the machine, of which the following is a description, has been invented:—

"This machine, which has been patented by Messrs. Best and Holden, has been tried at the works of the Chartered Gas Company, Westminster, for some time; and, during the period it has been in action, it has been subjected to some severe tests, with very good results. As applied at the Chartered gas-works, it is formed in two parts, one carrying the machinery for drawing, and the other that for charging the retorts. Each part consists of an under frame, formed of

wrought-iron girders, carried by four wheels running upon rails placed seventeen feet apart from centre to centre, these rails running longitudinally through the retort-house, parallel to the ends of the benches, and removed a short distance from them. The two parts of the machine are placed close together, and suitably coupled, the motion being transmitted from the charging portion (which carries the steam-engine and boiler) to the raking machinery by means of a coupling connecting the main shafts of each, as will be explained presently.

"We will first describe the charging machinery, which, as we have already stated, is carried on the same frame as the engine and boiler. The motive power consists of a pair of oscillating cylinders, six inches in diameter, and with a stroke of nine inches, which are supplied with steam by an ordinary vertical tubular boiler. The slide-valves are worked by the oscillations of the cylinders, and the engines are fitted with reversing gear. Near one end of the crank-shaft is fixed a pinion, which gears into a spur-wheel placed upon the main shaft of the machine, which shaft is carried by suitable brackets from the main frame, and is furnished at one end with a coupling, by which it is connected to the corresponding shaft of the raking machine. On the main shaft is placed a bevel wheel, which can be connected to the shaft at pleasure, by means of a clutch, the wheel driving another fixed upon a short vertical shaft, having at its lower end a bevel pinion, gearing into a bevel wheel, fixed to one of the carrying wheels of the machine. This arrangement gives the power of traversing the machine backwards and forwards at pleasure, the direction of the motion being governed by that in which the engine is driven.

"The charging machinery consists of a series of scoops, arranged so that they correspond with the mouth-pieces of the retorts, and carried by short shafts attached to their ends. The shafts to which the scoops are fixed are carried by bearings fixed to the front and back frames of a carriage, which is itself carried by rollers running on suitable rails fixed to the main framing. The traversing to and fro of the carriage on these rails is effected by a pitch-chain coupled to it, and passing over a chain-wheel on the main shaft, this wheel being connected to the shaft at pleasure by means of a friction coupling, which can be thrown into action by a lever, placed so that it can be conveniently acted upon by the foot of the engine-driver. At the end of each of the shafts carrying the scoops is fixed a pinion, these pinions gearing into a vertical rack, which slides in guides on the back frame of the carriage. The rack just mentioned is formed in one piece with another rack, which gears into a spur-wheel placed on a shaft supported by brackets from the carriage frame, this shaft having, at its outer end, an arm loaded with a heavy weight. When this weight is raised, it is held up by a catch, which falls into a notch formed in a disc fixed to the shaft, and prevents the latter from turning. When this catch is released, however, in the manner which we shall describe directly, the weight falls, and, by turning the shaft to which the arm is fixed, moves the racks, and thus turns the scoops over.

"The manner in which this machine is worked is as follows :—The scoops are each charged with the proper quantity of coal by means of hoppers leading from a coal-meter over head, and are then run forward into the retorts by means of the pitch-chain gearing. When they have thus been advanced the proper distance, a pin on the main frame comes in contact with the vertical arm of a bell-crank, the horizontal member of which forms the catch holding up the weight; and the latter being thus released, the scoops are turned over, and thus made to deposit the coal contained in them in the retorts. The engine is then reversed, and the scoops withdrawn; after which the weight is lifted, and the scoops returned to the proper position for receiving another charge. The raising of the weight is effected by means of a pinion on the main shaft, which can be connected to the latter by means of a clutch, this pinion gearing, when the carriage is brought back, into the spur-wheel which we have already mentioned as acting on the racks.

"The machine for drawing the charges is, like the charging machine, furnished with a carriage which can be traversed backwards and forwards by means of pitch-chains. This carriage supports three long bars or rakes, placed in a vertical row, at such distances apart that they correspond with the upper part of the retorts. Each rake is furnished at its end with a plate, which can either be set at right angles to the rake-bar, or can be made to project horizontally. This adjustment is accomplished by means of a rod sliding in guides fixed to the main bar of each rake, and having a rack at its inner end, which is moved by a pinion fixed upon a vertical shaft furnished with a hand-wheel. The pitch-chains moving the carriage are worked by chain-wheels fixed upon a countershaft at the back of the machine, the countershaft also carrying a spur-wheel, which is driven by a pinion placed on the main shaft, and connected with it when required by means of a clutch. The mode of working the machine is very simple. The machine having been properly placed, the rakes are run forward into the retorts, with the plates at their ends extended; and these plates being then lowered, the rakes are withdrawn, bringing the charge with them. In addition to the plates at their ends, the rakes are furnished, at two or three points in their length, with teeth hinged on their lower sides. Those teeth are hinged to the rake-bars, so that when the latter are run into the retorts, they close up against the under sides of the bars; but when the rakes are withdrawn, the teeth drop down and assist the plates at the ends in taking hold of the coals.

"The machine at the Chartered gas-works has been used to charge and draw retorts, set ten in a bench; and it has been worked with two rakes and two charging scoops, only the two lowest and two highest retorts of each bench being charged by hand. A bench is, however, now being set with nine retorts, these being disposed in three similar vertical rows, so that they

can be all worked by the machine. The machine may also, if desired, be arranged to charge the whole bench at once, as we have already mentioned. At present, the retorts at the Chartered gas-works have only been charged from one end by the machine, the other ends being charged by hand; but if the new system is fully carried out, there will, of course, be a machine for each end of the retorts. The machine is tended by four men — viz., an engine-driver, a man superintending the raking machine, and two men filling and attending to the coal-scoops; and it is found to be capable of drawing and charging a bench of retorts in about one-fourth the time required by hand labour. As, moreover, all the severe portion of the work is performed by steam-power, the machine can be kept going almost continuously; and it is thus expected that a pair of these machines, with their eight attendants, will replace about eighty men working on the ordinary system. When we consider the immense amount of labour involved in working the gas retorts of the London companies alone, it seems curious that machinery for the purpose should not have already been brought into regular use; and there seems to be but little reason to doubt but that it will eventually be generally employed in some form or the other. It is probable, also, that machinery will more generally be applied for handling the coal before it is supplied to the retorts, as well as for removing the refuse coke; and, indeed, at some of the new gas-works now being erected, labour-saving appliances of this kind are already being introduced."

Such an invention is, of course, not only of great value as affecting the lives of men employed in such works, but it has, also, to the gas companies a peculiar importance, which renders them more independent of manual labour, less in fear of strikes, and is, of course, a considerable saving in wages. The stokers at gas-works, whilst having full and laborious employment in winter, are differently placed in summer, when the demand for gas, of course, greatly decreases. In the long-day portion of the year, great numbers resort to brick-making, harvesting, and such other labours, strangely contrastive with that of their winter occupations. According to Mr. Colburn, from 4,000 to 5,000 men find employment in the gas-works of London in the winter-time, a large proportion of whom are thrown on their own resources as summer returns.

The fuel generally used in the gas-works of London, is the coke produced by the carbonisation of the coal in the gas retorts. The heat employed is sufficient to render iron retorts of a bright red; but the non-conducting character of clay retorts, requires that a higher temperature should be maintained, so as to extract as much as possible all the illuminating hydrocarbons of the coal. The temperature is judged of by what are called *sight-holes*, which are openings through the brickwork in which the retorts are laid; and thus the stokers, or firemen, have means of judging the amount of heat, and also of regulating it. At some gas-works in London, the furnaces are fed directly with the red-hot coke taken from the retort during drawing, which, as already mentioned, is done at the end of each six hours of the day (twenty-four hours).

The effect of heat on the coal is to render the coke, or remaining carbon in an impure form, highly porous; for the coal greatly swells, through the production of pores, as the hydrocarbonous gases escape. Hence gas-coke greatly differs from the coke made for railway and metallurgical purposes; the latter being close in texture, and so compact as to ring like a bell on being struck with a hard body. This latter result, perhaps, is chiefly due to the fact, that in coke ovens no pressure exists on the gas delivered from the carbonising coal, for the whole of it readily escapes up the chimney. In the gas retort, on the contrary, a certain amount of pressure is always exerted, from a variety of causes, to be presently explained.

As the coal is decomposed, and affords the gases required for illuminating purposes, it not only produces coke, but also a peculiar form of carbon, being analogous to graphite or plumbago, and greatly differing from ordinary gas-coke. This carbon, especially in iron retorts, accumulates as a hard dense mass on the top and sides. It is extremely objectionable, because, as a bad conductor of heat, it prevents the latter from rapidly passing from the furnace to the distilling coal, and, consequently, causes a loss of time and fuel. Clay retorts, especially those with double mouth-pieces, are not so liable to become thus coated. In all cases, however, the higher the pressure exerted on the gas escaping from the coal, the larger is the amount of this deposited carbon. It was formerly thrown away as an entire waste, being all but incombustible from its extreme denseness. Some years ago this substance was utilised for the purposes of science. For the information of those of our readers who are unacquainted with the requirements of the electrician, we may observe that, in constructing a voltaic battery, two solid elements, in all its ordinary forms, are necessary. One, usually zinc, to act as the positive; and the other, copper, silver, or platina, to become the negative plate of each cell of the battery. In the combination known as Grove's battery, zinc and platina are used, the former being surrounded with dilute sulphuric acid, and the latter with the strongest nitric acid. Platina being very expensive, and becoming brittle by repeated use, it became desirable to find a substitute for it. Iron was proposed; but it was found that the carbon deposited in gas retorts is an excellent material. Hence carbon batteries, so produced, have been largely used of late years. Also, in the production of the electric light by the disruptive discharge of the voltaic battery, points or terminals, made of gas carbon, have been largely adopted. It must be added, that however these uses of this carbon may be interesting and valuable to the man of science, they are extremely limited; hence it is an object with the gas company to reduce the production of this carbon as much as possible. The double

opening—that is, at each end of the long retorts previously described—greatly lessens the production of, or removes, the carbon, by the through current of air that impinges on it as the retorts are open during the process of drawing. As the gas is produced during the distillation of the coal, it passes through upright pipes, called ascension or stand-pipes, which rise from the mouth-pieces of the retort, already described at p. 579, *ante*. These vary from four to six inches in diameter, and generally are fixed at each end of long retorts, on each mouth-piece; although this plan is not universally adopted.

The annexed cut gives a sectional view of the retort, pipe, and hydraulic main shortly to be described. In it A represents the retort, of which one end only is shown. In respect to the long kind, and in which the coal is undergoing distillation, B is the lid covering the mouth-piece of the retort; C, the ascension or stand-pipe, through which the gas passes from the retort, A, to the hydraulic main, D, by dip-pipes, so called because they reach into the water.

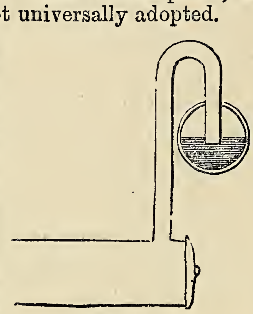


Fig. 416.

The hydraulic main is a cylindrical tube, varying from fifteen to thirty inches in diameter, and extending throughout the whole length of the benches of retorts, horizontally, in the gas-house. It is half filled with water, represented by the shaded portion of D in the preceding cut; and by means of a regulating apparatus, any addition to it, so as to raise the level of the fluid, is prevented. The ends of the ascension-pipes from the retorts dip into the water of the hydraulic main, into which, whilst the gas produced can readily flow, it at the same time cannot return to the retort, for the water forms a kind of seal. Hence, if one or any number of retorts are in course of being "drawn," the rest that are delivering gas can be allowed to go on without the least danger of any of the gas escaping through the opened retorts.

This ingenious contrivance may be popularly illustrated as follows:—In the ordinary house sink-trap, a perforated disc is attached to a cup that fits loosely into a kind of basin. This permits the water readily to run down the drain, but entirely prevents the upward passage of any gases generated below. The action of simply blowing into a basin of water by means of a tube or straw, is precisely similar to that effected by the gas as it issues from the ascension-pipe, and passes through the water of the hydraulic main. In all these, and many other instances of a similar kind that we need not specify, the water forms, at such trifling pressure, an air-tight joint that effectually prevents the back passage of either air or gas.

The hydraulic main is thus the "grand canal," by which the gas, produced by the distillation of coal, is conveyed to the various apparatus intended to purify it, and to the gas-holders which store the gas. But it also performs another and most important office—that of collecting all the condensible matters afforded from the coal, such as tar, ammonia, and a host of others that we shall not at present name.

Of course water cannot exist in the hydraulic main long at a temperature greater than boiling water; and although the heat of the gas, as it passes from the coal, is very great, still the water does not greatly rise in temperature. Now, with the exception of the ammonia given off from the coals, nearly every other product of coal distillation is liquid at a temperature greater than that even of boiling water; hence they are arrested by the hydraulic main, and can, by suitable contrivances, be easily drawn off, the main being supplied with fresh water whenever necessary.

Much difference exists in respect to the amount of matter deposited in the main, whether solid or liquid; and this depends on the nature of the coal used. If cannel coal be employed, the main becomes rapidly filled with tarry matter, and must be cleaned in each four months of constant use; whilst, with Newcastle coals, it will remain unobstructed for a very much longer period.

As already mentioned, the hydraulic mains are usually cylindrical, and at one time were made of cast-iron. But recently (as in the iron girders of railways), riveted vessels of wrought-iron have been employed, of a rectangular form, and fitted with doors, traps, &c.; by means of which the tarry matter and gas liquor generally can be readily removed. And here it may be noticed, that the tarry matter being insoluble in water, as it enters that liquid in the hydraulic main, soon sinks to the bottom, displacing a portion of the water; and, therefore, if not removed, would soon render the main useless by driving off all the water from it. Of course the ammonia forms a solution not to be distinguished physically, except by specific gravity, from water itself. On an average, a ton of good Newcastle gas coal yields ten gallons each of tar and ammoniacal liquor. Cannel coal, being much richer in carbonaceous matter, gives from thirteen to fifteen gallons of tar, whilst the ammoniacal liquor is often absent. We have tested many gas supplies in Scotland, and, in most cases, could not detect a trace of ammonia, owing to the absence of nitrogen in the coal. Lesmahago cannel, whilst containing a small proportion of this element, is so managed, in respect, at least, to the purification of the gas, that all the ordinary means of detecting ammonia at the burners, as directed at p. 574, *ante*, failed to show the slightest presence of that compound.

Formerly the gas proceeded direct from the retorts, by the hydraulic main to other parts of the apparatus, simply by its own pressure; but exhausters are now generally employed to withdraw the gas. The pressure in the retort is thus reduced to a minimum; and another advantage arises in the fact, that much less carbon

is deposited in them, of the kind previously described. At times the exhauster is placed between the condenser and hydraulic main; but in other cases the exhauster is made to act on the gas in connection with the condenser, the latter being placed next the main; and hence the exhauster acts on the gas after it has passed through the condenser. These arrangements may be briefly described as follows :—

Of course, as the gas issues from the retort, or even the hydraulic main, its temperature is high; but not only so, it contains a large quantity of tarry matter, united with ammonia, which has the property of retaining a portion of tar in gaseous solution. A considerable portion of tar and ammonia, with other condensible matters, are deposited in the hydraulic main, as already mentioned. Now the object of the condenser is to remove, as far as possible, other volatile matters that have escaped the action of the water in the hydraulic main; and this is effected by causing the gas to pass through an extended series of iron tubes, exposed to the cooling action of the atmosphere, but commonly aided by water trickling over their surface; the evaporation of the fluid carrying off both the latent and sensible heat of the gas.

Before we describe the exhauster, now so universally found at gas-works, another important apparatus or arrangement should be mentioned, called the *scrubber*. For this purpose, we shall quote from *Engineering* some able remarks by Mr. R. H. Patterson, the eminent gas engineer, on the forms of Gas-washers and Gas-scrubbers that are now in use :—

"Within the last few years a marked improvement has commenced in the purification of coal-gas; and it is to be hoped that further progress in this direction will soon be attained. Undoubtedly the grand impulse to this progress was given by Parliamentary legislation; and ere long it will be admitted by the gas companies themselves that the legislative penalties upon gas impurities which they (naturally enough) so vehemently opposed have conferred upon them a positive benefit. Thereby the companies have been compelled to direct their efforts to the better purifying of the gas, rendering it more acceptable to their customers; while at the same time they have come, or are coming, to see that the new processes and apparatus thus rendered necessary will be actually profitable to themselves. In gas-making, as in all branches of manufacture, the best kinds of apparatus or of processes, even although these be (which is not necessarily the case) more costly at first, are the most economical in the end.

"As regards new forms of apparatus, it is in the washers and scrubbers that the greatest progress is at present observable. The mental activity in this department is evidenced by the number of new kinds of washers and scrubbers recently patented and otherwise brought under the notice of the gas world—viz., Anderson's, Livesey's, Kirkham's, and others. We are sorry to think how long it will be before these appliances—some of them admirable—will come into general use. The *vis inertiæ* is very strong in the gas companies. The younger school of gas engineers are quite ready, many of them are most anxious, to try any new process or apparatus which promises to be an improvement. But there is this great difficulty in their way, that their works are already fitted up with the old apparatus; and so long as they can 'get along' by means of the present plant, directors are naturally, and to some extent reasonably, reluctant to displace it. Hence, as regards the new kind of washers and scrubbers, it will be long before they come into general use, although the superiority of some of them is manifest even at sight. We are glad to know that, where extensions of plant are necessary in the metropolitan gas-works, one or other of the new kinds of apparatus are being adopted.

"The kind of scrubber at present most generally used, viz., the 'tower-scrubber,' filled with coke, has had its day (1880). As perfected by Mr. Mann it was a vast improvement upon any of the old kinds of washer—in some of which (still to be met with in provincial towns) the gas bubbles tumultuously through the water in globes as big as a man's head, and in all of which there was the fatal defect that the gas was washed with the same liquor, instead of being made to pass through clean water last of all. This latter point was the one which gave the distinguishing superiority to the scrubber over the washer. In the scrubber, in all its forms, the water enters at the top and trickles down, so that the gas in passing upward always comes in contact with clean water at the outlet, whereby, if the scrubber or series of scrubbers be of sufficient size for the gas-make, the ammonia can be wholly extracted. The other advantages claimed for, and partially possessed by the scrubber over the old washers were, first, that it gave less 'back pressure,' and, second, that the purification was effected by means of a smaller quantity of water (owing to the water being finely distributed over the coke, so as to present a maximum of wet absorbing surface to the gas), whereby the ammoniacal liquor was obtained of greater strength. But the latter of these advantages was not a necessary concomitant of the scrubber, but arose merely from the very defective form of the old washers. It is needless to say that any form either of washer or scrubber can be employed so as to raise the liquor to the required strength, merely by retaining the liquor for a longer time in one of the washers, or by returning it into *one* of the scrubbers while using the other vessels of the series in the ordinary manner.

"No better modification of the tower-scrubber yet exists than that known as 'Mann's,' and Mr. Mann was the first gas manager who gave intelligent care to improve the scrubber. It is also the fact that the ammonia purification as carried on by him at the Blackfriars works used to be, beyond all comparison, the best in London. From the very outset of the daily official testings, the gas from the Blackfriars works was absolutely free from ammonia. There used to be about a grain or half a grain of ammonia in the gas as it left the scrubbers, but this small

residuum was absorbed by the moisture in the subsequent oxide of iron purifiers. The Blackfriars works have for some years past been abandoned, and are now demolished—their place knows them no more; but to this day there is not a single London gas-works—certainly not one of those subjected to the official testings—where the ammonia purification is so perfect as it was at these old works, so ably managed by Mr. Mann. Even at the large new Beckton works, where the scrubbing power is on a much larger scale than at the Blackfriars works, the ammonia purification has been inferior in its results, not from deficiency of apparatus, but from an inferior system of employing it.

"These perfect results obtained at the Blackfriars works—at a time, too, when gas managers in general regarded it as impracticable to remove the last traces of ammonia—naturally created a high impression as to the excellence of the Mann scrubber. Nevertheless, the perfection of the ammonia purification at the Blackfriars works was by no means due solely, or even chiefly, to the kind of apparatus there employed, but mainly to the clever and intelligent manner in which the apparatus was worked by Mr. Mann. It is true—and he deserves to have the fact recorded—that Mr. Mann was the first to give able and thoughtful attention to the internal arrangements of the coke-scrubber. He gave successful attention to both of the two important parts of the apparatus,—namely, both to the distribution of the water supply, and to the arrangement of the coke. His brush-wheel at the top distributes the water as perfectly as it can be done; and he arranged the coke in three compartments, with two intervening open spaces wherein the gas could redistribute itself and ascend equably through each tier of coke, thereby lessening the danger of the gas 'blowing' a passage, or two or three separate passages, for itself from bottom to top, as the gas always tends to do after the coke-scrubber has been in action for such time that the interstices in the coke begin to be clogged with tar.

"The distributing brush-wheel in Mann's scrubber also serves as a cover to the apparatus, partially protecting the upper part of the vessel (where the most difficult portion of the work is done, viz., the extraction of the last grains of ammonia) from the sun-heat in summer, which by warming the water impairs the purification of the gas. On several occasions at Beckton, in the summer of 1871, the temperature of the gas in the uppermost part of the first scrubber has been found by the writer to be raised by the sun-heat to 110 and 112 deg. Fahr.

"But all this of itself would not have sufficed to achieve the above-mentioned results, but for the mode of working employed by Mr. Mann. He made a nice adjustment of the two factors of the case, namely, the quantity of gas which had to be purified, and the number and size of his scrubbers; and instead of sending the whole of his gas through each of the four scrubbers in succession, he split his gas into four streams, each of which passed through a separate scrubber. And his total gas-make and the size of his scrubbers were such that each of his four gas streams was thoroughly purified in passing through its single scrubber; while the ammoniacal liquor so formed was so strong (fully '14-oz.') that when mixed with the weak liquor (about 5 or 6-oz.) from the condensers, the whole of the liquor possessed the requisite commercial strength of '10-oz.,' that is, requiring 10 oz. of sulphuric acid to neutralise the NH_3, in a gallon of the liquor. When scrubbers are employed solely for the purpose of extracting the ammonia (but not when they are employed also for decarbonating the gas, as by one of the writer's new processes of purification), this manner of working them is certainly the best; firstly, because when the gas is passed in separate streams each through a single scrubber, the back pressure is proportionately less than when the gas is passed in a single stream through the whole of the scrubbers; and, secondly, because in this way the special advantage of the scrubber (viz., that the gas can be brought in contact with clean water in the upper part of the vessel) is turned to account in each vessel; whereas if the gas be passed through the whole series of scrubbers, this special advantage of the apparatus is lost as regards all the vessels save the last one.

"But if the tower-scrubber be looked at with a fresh eye, its defects will be at once apparent. This vessel, frequently 40 feet and sometimes even 60 feet high, and 12 feet or 15 feet in diameter, is filled with coke, bricks, or such-like materials, which have no effect in purifying the gas. The special object of washers and scrubbers, at least as now employed, is to extract the ammonia; for which purpose all that is needed is to bring the gas in contact with water, which substance, from its remarkable affinity for NH_3, is by far the best and most economical means for extracting this impurity. But the tower-scrubber is filled with coke or bricks; and from experiments made by Mr. Mann, it appears that the coke occupies fully two-thirds of the vessel—a great waste of space, only explainable by the process of 'development' through which the scrubber has passed.

"The origin of the scrubber, we have been told on high authority, is 'involved in obscurity.' Its real history, however, was this: In old times the work of gas purification was carried on in a hap-hazard and most imperfect manner. The first object of gas manufacturers was simply to get rid of the tar—which was done (so far as it was done) by cooling the gas, at first by washing the gas with water, which was the origin of washers; but by-and-by it was found that the tar could be largely removed by passing the gas through 'breeze,' coke, and such-like substances, and this was the origin of 'scrubbing.' But by-and-by, during the last quarter of a century, it was found that the ammonia could be extracted by water, instead of (as previously) by chemicals; and thus, while in some gas-works the washer was retained and employed for this new purpose (in addition to its old use in removing the tar by cooling or condensation), in other gas-works it appeared a

happy thought to employ water in the coke-scrubbers, so as to absorb ammonia, while also 'scrubbing out' the tar. This was the origin of the present or wet scrubber. In fact, the scrubber was not designed specially, or even primarily, for the extraction of the ammonia; but, by passing water through it, the old dry scrubber was made more or less efficient for this new purpose. At the same time, however, the coke-scrubber was thereby rendered less efficient for its original purpose, viz., the extraction of tar; for the tar does not settle on a wet surface to the extent which it does upon dry coke.

"Thus the wet coke-scrubber has been in its origin, and still is even at its best, a makeshift. Like the old washers, its *original* use was chiefly to get rid of the tar; and when ammonia purification by means of water was recognised as a necessary and valuable process in gas manufacture, the tower-scrubber was employed, or was meant to be employed, primarily and chiefly to extract the ammonia. Hence, we repeat, it is a makeshift, destined to give place to a better form or forms of apparatus. It seeks to combine two different objects which impede and conflict with one another. To extract the tar, the scrubber is filled with materials (coke, bricks, &c.), which are inert and useless for the extraction of the ammonia, producing a loss of space, or waste of apparatus, which is increased enormously in the course of working, owing to the interstices, the space designed for the contact between the water and the gas becoming greatly narrowed, and almost choked up by the deposits of tar.

"It was Mr. G. Anderson who first pointed out the inherent defects of the scrubber; and, at the same time, he struck the key-note of improvement, directing invention into the best course, and in which it has since so rapidly progressed. Indeed, Mr. Anderson's name deserves to be mentioned in almost every field of progress in gas manufacture. Possessing a vigorous intellect, and still in the prime of life, he does not allow habit or the traditions of the past to obscure the real facts of the case. He is one of those men who like to know 'the reason why;' and his knowledge of the broad principles of physical science enables him to see in what direction improvement in gas manufacture is to be looked for as a practical question.

"In a paper which he read before the British Association of Gas Managers in 1874 (which obtained the prize for that year), Mr. Anderson called attention to the great importance of doing the work of washing or scrubbing efficiently, and maintained that, if properly constructed, the washer was a much superior apparatus to the tower-scrubber, which for many years previously had been (and, as washers were then constructed, very rightly) the favourite apparatus, and in London the only one employed. At that time, and, indeed, for some years before, Mr. Anderson had been making improvements in the washer; and since then, in 1876, he has devised a remarkably good apparatus of this kind, which we shall deal with first among the new washers and scrubbers to be passed in review.

"The main feature of the Anderson Washer—or, as he terms it, a 'combined washer and brush-scrubber,'—is a brush-wheel revolving in water in the opposite direction to the gas-stream; and as there are several compartments of this kind, one above another (varying in size and number with the quantity of gas to be purified), this apparatus includes the best feature of the tower-scrubber, viz., the gas passes upwards through purer water, or weaker liquor, till it reaches the uppermost compartment where the pure water enters.

"The interior of each compartment is fitted with an axis from which projects a brush, made of whalebone or any suitable material. Mr. Anderson prefers to use the reedy material commonly employed in brooms for sweeping stables, having been led to adopt this material from noticing its good qualities when used by his gardener in the stable-yard. There can hardly be a better, certainly not a cheaper material, inasmuch as, besides its suppleness and durability, each stem keeps its position well, and does not get into a mass—an important quality, since the perviousness of the brush is requisite for the efficient distribution, or application of the purifying action of the water. At each revolution, the brush dips into the water (which occupies the lower portion of the compartment) and comes out dripping; so that the gas is brought in contact, not only with the wet surface of the brush, but also with the drops of the dripping water. The semicircular top of each compartment forms the bottom of the one above. The revolution of the brush-wheels is effected by a rod, worked by steam, carried down one end of the machine.

"At the bottom of the apparatus, and before the gas ascends into these brush-wheel compartments, there is a simple washer, which is so placed and employed for the purpose of cleansing the gas from the finer tarry particles which usually escape from the condensers—whereby the brush-wheels are kept clean and unclogged. This washer at the bottom of the apparatus is one which Mr. Anderson devised many years ago, when he first began to give attention to the defects of the old kinds of washer, with the view of improving its structure, so as to bring the simple employment of water into use again in preference to the wet scrubber, which for so many years had been the favourite and also superior apparatus. It consists of a trough of water into which a series of serrated plates dip at intervals of about a foot; and if the gas really passed up and down (out of and into the water) between each of these serrated-edged plates, this kind of washer would be a remarkably good one. It is doubtful, however, if the gas will act so obligingly; it will probably take its course through the vessel on the principle of least resistance—the pressure of the gas 'unsealing' a good many of the plates with a single rush. Nevertheless, this early-devised washer of Mr. Anderson's is found in practice to be tolerably efficient; and, placed as it is here, it is perfectly adequate for its purpose of condensing and washing out the finer particles of the tar, so as

to keep the brush-wheels in the upper portion or main body of the apparatus unclogged. The pressure required for working this bottom part of the apparatus is decidedly a disadvantage; but it is not an essential part of the apparatus, and only the brush-wheels ought to be employed when the condensing apparatus is sufficient.

"In his original draft of this apparatus, Mr. Anderson designed it horizontally—the flow of water continuously through all parts of it being effected by placing each compartment on a slightly higher level than the subsequent one. But the vertical arrangement of the compartments, adopted in his perfected invention, is manifestly much better—especially as saving space, which is so important a consideration in all urban gas-works. Moreover, any increase in the gas-make (and the gas-make is always increasing) can be readily and simply met by adding one or more compartments at the top of the apparatus. In fact, Anderson's Washer offers perfect facilities for a great increase of size, and for every refinement of ammonia purification that can be desirable in gas-works.

"On the very face of it, this new apparatus of Mr. Anderson's is a remarkably good one in every respect. In the first place, it has the merit of great simplicity; it can hardly get out of order, and is easily taken to pieces should the brushes need cleaning; while the apparatus itself is readily capable of extension in size, by the mere process of addition; secondly, it brings the gas into contact with water far better than any of the old kinds of 'washers,' or even of the best kind of tower-scrubbers,—*i.e.*, the purifying action of the water is greater within the same space; and, thirdly, as a consequence of this, the cost of the apparatus, relative to the amount of work done, is less than that of the tower-scrubber; finally, as regards its power of extracting the last few grains of ammonia (which is absolutely impossible with any previous form of the 'washer'), this new apparatus rivals the tower-scrubber in this—that the gas is passed through pure water last of all, in the uppermost compartment. The degree of purity of the water in the uppermost compartment, of course, will depend entirely upon the size of the apparatus and the quantity of gas passed through it. The tower-scrubber itself cannot contain pure water even at the top of it, when the quantity of gas passed through it is greater than the scrubber is capable of purifying from ammonia. The best apparatus in the world will not of itself insure a proper purification of the gas. What is indispensable is to manage the operations as Mr. Mann did with his tower-scrubbers, namely, to adjust the quantity of the gas to the purifying capacity of the apparatus, so that the whole of the ammonia be extracted before the gas reaches the top part of each vessel, where the pure water enters.

"The Anderson Washer is suitable for gas-works of every size, and not least so for the smaller class of works, owing to its perfect simplicity and also cheapness of construction. It is only in the London gas-works, and a few others of first-class magnitude, that it is necessary to thoroughly purify the gas from ammonia; and for these works this washer has been found to be very efficient. Where the gas must be purified even from the last grains of ammonia, the top compartment ought to be treated somewhat like a 'reserve-purifier'; that is to say, the gas should be passed through the apparatus only in such quantity as can usually be purified from the ammonia before entering the top compartment, in order that the water in this uppermost compartment may be so pure as to insure that no ammonia goes forward from the apparatus in the gas; for it must be borne in mind that ammonia is so volatile an impurity that if gas be washed with ammoniacal water (however weak the 'liquor' may be) it is impossible to prevent some portion of the impurity from remaining in, or even being returned into, the gas. Were it desirable in any case (and such cases must be extremely few) to increase the delicacy of action of this washer without increasing its size, this might readily be done by substituting for the top compartment two compartments of half the height (each fitted with a brush-wheel of half the diameter of those employed in the other compartments), whereby the important point of bringing the gas into contact with pure water last of all could be more readily insured.

"One of the first places where this washer was erected was the St. Alban's Gas-works; and in the published report, dated April 27, 1877, which the engineer of those works (Mr. A. F. Phillips) made on the new apparatus, and in which he speaks of it in the most favourable terms, the two points most worthy of notice are: (1) that 'the brushes cause no appreciable increase of back pressure;' and (2) that the apparatus 'performs its work more efficiently than the tower-scrubber I have, while only about half the height, and not one-fourth its weight or capacity,'—in other words, the ammonia purification was better done in about one-fourth of the space and size of apparatus.

"The thorough efficiency of this new washer (or 'combined washer and scrubber') was demonstrated some eighteen months ago (1878) at the Vauxhall works of the Phœnix Company, where, thanks to the friendly courtesy of Mr. Woodall, I had an opportunity to see this new apparatus at work, and to ascertain what it actually does. The apparatus, as erected at Vauxhall, consists, besides the trough or tar-washer at the bottom, of five tiers or compartments, each containing a brush-wheel 4 feet in diameter and 10 feet in length; so that the size is about 22 feet in height, 4 feet in depth, and 10 feet in breadth. The quantity of gas passed through it was about 35,000 feet per hour, and the quantity of water was 18 gallons per ton of coal. The purifying power of the vessel may be shown, in the first place, by the state of the water or liquor in the several compartments. The following shows the ammoniacal strength of the liquor in those compartments really at work—'10-ounce' liquor being liquor requiring 10 ounces of sulphuric acid to neutralise the ammonia in a gallon of it:—

Bottom trough, or tar-washer	10-oz. liquor.
First brush-wheel compartment..	8 ,,
Second ditto	3 ,,
Third ditto	only a trace of ammonia.
Fourth ditto	Clean water.
Fifth ditto	,,

"Manifestly the apparatus was underworked, so that a larger quantity of gas might have been passed through it.

"One of the testings made at Waterford appears to show the full power of the apparatus, and is, therefore, worth giving. The following table shows the strength of the liquor in each compartment, the quantity of water passed through the washer being 11 gallons per ton of coal carbonised:—

	Strength of liquor.
Bottom trough	16-oz.
First brush-wheel compartment ..	14
Second ,, ,, ..	5·4
Third ,, ,, ..	2·2
Fourth ,, ,, ..	0·4
Fifth ,, ,, ..	pure water.

"It is almost needless to add that 15 ounces or 16 ounces of liquor is more than enough, when mixed with the weak liquor from the condensers, to make the whole ammoniacal liquor produced on the works up to 10-ounce strength, which is the highest strength desirable.

"We may add that Mr. Anderson in some cases makes a slight alteration in the mode of working his brush-wheels, namely, by making the top brush-wheel to revolve along with the course of the gas, instead of contrary to it, as is the case in the lower compartments. The object of this modification of the apparatus is to guard against the pressure of the gas forcing some of the water into the outlet-pipe for the gas, which is about two inches higher than the inlet-pipe on the opposite side of the compartment; but by making the brush revolve along with the gas-stream, the pressure of the gas on the water can be reduced to the desired point. A similar gas-pressure upon the water, of course, exists in all of the compartments; but in each of the lower compartments any water thus forced into the ascending outlet-pipe for the gas simply falls back again into the compartment."

After describing other forms of gas-washers and scrubbers, Mr. Patterson draws attention to the Livesey washers, which he alludes to in the following terms :—

"We now come to two new kinds of washers devised and patented by Mr. G. Livesey, both of which are highly novel and ingenious, and very interesting in their working.

"Some five years ago (1875), when visiting the South Metropolitan Gas-works, I found Mr. Livesey experimenting with a 'Woulfe bottle;' and I remember his remarking that he found the absorption of ammonia in this apparatus much superior to what was attainable by any form of washer or scrubber then in use. The principle of his new washers is that of Woulfe's bottle—that is to say, the gas is passed in thin streams through the water; and the application of the principle is highly ingenious and the result of much investigation.

"The peculiar feature of these washers is the marvellously fine state of division in which the gas is exposed to the action of the water. In the first devised apparatus, this result is attained by making the gas enter the water through a plate perforated with fine holes, and then pass through another such plate placed within the water. The plates are of thin iron, perforated with holes about half an inch from one another, and so small that a pin-head would close them. Through these holes the gas passes in thread-like streams, causing the water on the surface of the second plate (from which the gas escapes into the outlet chamber) to bubble up in froth to the height of from 6 inches to 9 inches—the foam or gas-boils being only from $\frac{1}{8}$ inch to $\frac{3}{4}$ inch in diameter.

"The drawing, Fig. 418, at page 589, gives an end of the apparatus, showing the longitudinal tubes in section. The gas enters the gas-chamber at the top, and passes down between the longitudinal tubes to the water-line; then, depressing the water, it passes through the first perforated plate (which forms the lower and inclined part of both sides of the tubes) into the water within the bottom part of the tubes; then rises through the second and horizontal perforated plate, escaping in foam into the upper part of each covered tube, and, finally, passing along to right and left, escapes at either of the open ends of the tubes. The passage of the gas produces a circulation of the water, which, rising through the perforated plates into the upper part of the covered tubes, rushes off (as the gas does) to either end of the tubes, from which (while the gas goes upwards) it descends into the tank to resume the same course of circulation.

"To show the actual working of this apparatus, the diagrams (Fig. 419, at page 589) are given, in which one of the longitudinal tubes is represented in section. No. 1 shows the tube when the apparatus is ready for work, but before the gas is admitted. No. 2 shows the tube just after the gas has been admitted, and has by its pressure lowered the water *outside* the tube and raised it *within*, but before the action has fully begun. No. 3 shows the tube when the apparatus is in full action.

"I may observe that where two or more of these washers are employed together, the froth or foam never rises so high in the first of them (where the crude gas enters) as in the subsequent ones—an effect which I have no doubt is owing to the tarry or oily matter largely contained in the liquor in the first washer of the series, which keeps down the foam.

"The other and later-devised apparatus of Mr. Livesey's proceeds on the same principle as the one just described; but its construction is entirely different. It attains the same object as the former one, but in a much simpler and (if it prove equally efficient) superior manner.

"The origin of it was thus:—In the course of his experiments with his horizontal perforated plates, Mr. Livesey found that if any gas at all was admitted below the plate and passing upwards through it, the water would stand on the upper side of the plate to the depth of several inches, without descending through the fine holes. Of course the gas when passing through an apparatus always exerts a pressure which varies with the velocity (or quantity) of the gas; but, in addition, there is a friction and resistance to the descent of the water owing to the smallness of the holes or perforations. Finding that water would thus stand to as great a depth as was requisite on the upper surface of a horizontal perforated plate, while the gas passed up through the holes and through the water, Mr. Livesey has made his newest washer to consist of a series of horizontal perforated plates, the water flowing along the upper side of each, and then descending at one end into the next, and so on.

"Externally, this No. 418 washer looks like the well-known apparatus (occasionally used in gas-washing) called "Coffey's still;" but it has this great difference and vast advantage that the gas not merely passes over the surface of the water in each tray, but also rises at every part of the tray through the holes and through several inches of water, which it throws into foam.

"I was enabled to watch Mr. Livesey's investigations in connection with his new washer, No. 417, from the outset, and some of the effects produced were unexpected as well as valuable. The deep foam generated by the passing of the gas through the finely-perforated plates employed in both of his washers was a result unexpected by Mr. Livesey, and was a most agreeable surprise to him. Indeed, as regards the washing of gas by passing it through water, it is impossible to conceive any result superior, or even equal, to that attained in both Mr. Livesey's washers. As one inch of water is thrown into foam 6 and even 9 inches deep, the contact between the gas and the water is the most perfect conceivable. It also rapidly removes the tarry particles left in the gas by the ordinary condensing apparatus.

"Mr. Livesey used to conduct his ammonia purification by means of tower-scrubbers fitted with closely-arranged ¼-inch deal boards set perpendicularly; and, as his make of gas has largely increased, he still employs these scrubbers with three of his No. 417 washers placed before them. He has not made any exact testings of the gas to determine the relative purifying power of his old scrubbers and new washers; but he estimates that one of these new washers (of the No. 417 kind) is as efficient as three of the tower-scrubbers, although one of these scrubbers costs more than three of his new washers.

"In conclusion, it may be observed that, where possible, I have stated the actual purifying power of the several new washers or 'washer-scrubbers,' which have been described in this series of articles; for this is really the most important matter of all, the value of any apparatus being entirely represented by its cost and its working power. I may add that one of the greatest *desiderata* in gas manufacture is the ascertainment of the relative value (*i.e.*, cost and working power) of the very numerous kinds of apparatus at present employed in gas-works. The only attempt of this kind hitherto and very imperfectly made is to be found in some of the reports of the Gas Referees in 1870-71, containing statistics and comparative statements which I collected and prepared of the ordinary purifying apparatus then employed in several of the London gas-works; but until this work is done thoroughly, and is applied to the apparatus for *making* as well as purifying the gas, gas manufacture can never be conducted in a scientific and properly efficient manner; and, from retort-settings down to washers and condensers, no engineer in constructing new works will be able with certainty to decide upon the best kinds of apparatus, viz., those which give the greatest results at the least cost."

The importance of the exhauster has been already alluded to, in its office of removing the gas from the hydraulic main, whether placed between that and the condenser, or outside of the latter as diminishing the amount of deposited carbon in the retort, and otherwise facilitating the manufacture of gas. On the history of the exhauster Mr. Colburn remarks as follows:—

"Mr. Grafton, the original patentee of the clay retort, is said to have been the first to show that, by pumping the gas from the retorts, so as to relieve them from the accumulated resistance of all the water-joints which the gas encounters on its way thence to the gas-holder, the furring of the retorts with carbon was in a great measure prevented. The accumulated pressure often amounts to 33 inches of water, 28 inches being common, when we include the dip of the pipes through which the gas enters the hydraulic main. With exhausters a partial vacuum is often maintained in the main, so that, if an opening be made, air will rush in instead of gas coming out. In the retorts, however, a very slight pressure, equal say to one inch or two inches of water, is maintained; the difference between this plenum and the partial vacuum in the hydraulic main being accounted for by the resistance offered to the gas by the dip of the pipes —say three inches—into the tar in the main.

"The first exhausters were reciprocating pumps; a sheet-iron cylinder, open at the bottom, and having a flap-valve opening upwards at the top, being made to work up and down, with its lower edge in water, around the rising end of a pipe admitting the gas, and having also a valve opening inwards at its top; the whole apparatus being enclosed in a gas-tight case. . . . . These were very much cheaper in first cost than Beale's exhausters, now used; but the whole plan finds few advocates now. The friction of the apparatus, although moving freely in water, was found to be considerable, and it imparted objectionable fluctuations of the gas, causing the water-gauge and the lights at the burners to oscillate violently.

"Mr. Beale, of Greenwich, produced a rotatory steam-engine many years ago, which, by

way of bantering a distinguished opponent of that class of motors, he named the 'Anti-John-Scott-Russell Steam-engine.' A considerable number of these steam-engines are still at work; and there are many besides the patentee who have much faith in their ultimate triumph over reciprocating engines. One, of small power, drives all the machinery in Mr. Beale's own workshop, at a very trifling cost for repairs, the expenditure for fuel being no more than for any ordinary engine of equal power. At the South Metropolitan Gas-works one of these engines is employed for driving the exhausters, and another for hoisting coal from the canal-

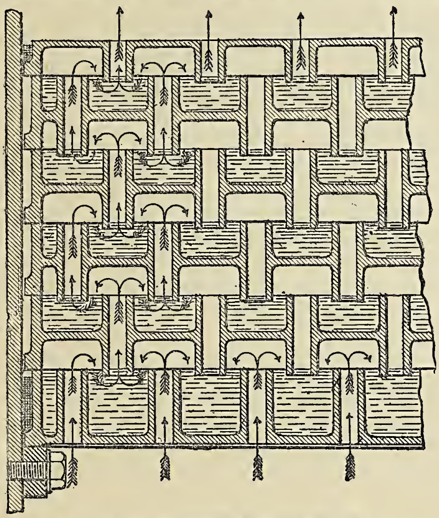


Fig. 417.—Livesey's Gas-washers.

boats coming up alongside. But Mr. Beale has found, altogether, the best market for his engines among the gas companies, who purchase them for exhausters. Nearly every gas company in London uses them; the motive power, in the majority of cases, being a little upright trunk engine, of neat design and fine workmanship, made by Mr. Beale, and fitted up on the same base-plate with the exhauster. . . . .

"Mr. Beale's exhauster consists of a stationary cylindrical case, with a horizontal axis within which revolves a shaft placed eccentrically with respect to the axis of the case, and carrying two flat plates or pistons, adjusted to fit accurately to the internal surface of the case. The principle is identical with that of the majority of rotatory engines and pumps. The tarry particles which, even after the gas has passed the condenser, follow it to the scrubbers, keep the wearing surfaces of the exhauster well lubricated."

Beale's patent exhausters have been the subject of many improvements, and are now almost universally employed in our gas-works. We quote the following remarks in illustration of the value of exhausters generally, and on properly sealed retorts:—

"It has been computed by practical engineers that an average saving of from 300 to 500 cubic feet of gas per ton of coals will be effected by the removal of nearly all pressure from the interior of the retorts during the process of carbonisation. This computation may be subject to much fluctuation, but in its practical argument it claims very earnest attention. The rapid development of scientific means and

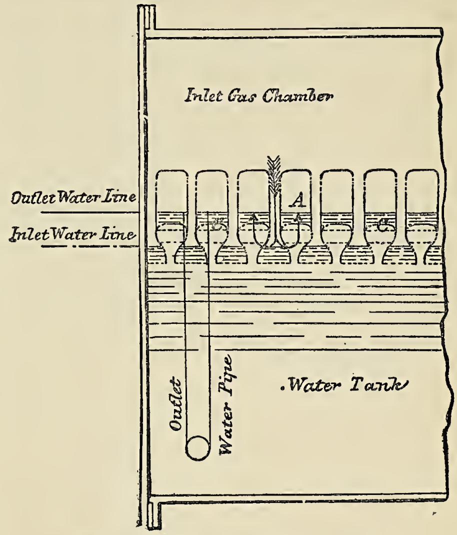


Fig. 418.—Livesey's Gas-washers.

apparatus for producing *Light* renders it impossible to ignore any effective appliance which largely augments salable production, which will considerably reduce the wear and tear of plant, and which greatly economises the cost of the manufacture of gas in its first and most costly operation. The very large interests involved, and the scrutiny exercised in the comparison of statistical reports, invests the subject of non-

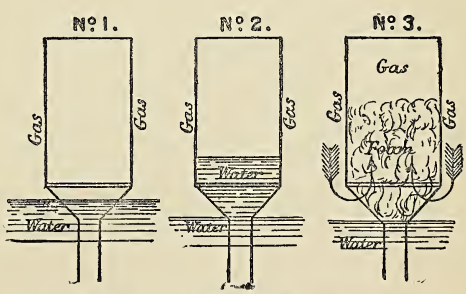


Fig. 419.—Livesey's Gas-washers.

sealed retorts with much greater importance than it has hitherto commanded; by a variety of methods the substantial fact has been established, viz., that, with such volatile fluids as coal-gas contains, it is of paramount moment that they shall be taken beyond the sphere of the hydraulic main before they are subjected to such violent action as an excessive pressure of *seal* (where it exists) constantly incurs. Hence

it is resolved, by almost universal consent, that the *seal* in the hydraulic main shall no longer be an arbitrary and constant obstruction, but a controlable and useful factor in the elaborate system of gas manufacture.

"The great economic advantages resulting from the maintenance of a minimum amount of pressure in the interior of gas retorts during the hours of carbonisation, which permits a free and steady exit of gas therefrom, are well known to gas engineers, yet the employment of means to effect such conditions are rather exceptional than general. It is, however, generally admitted that the greatest loss of gas prevails during the process of manufacture in unsound and defective retorts, hence it is sound policy, as far as practicable, to prevent it.

"In all gas-tight apparatus, such as hydraulic mains, exhausters, scrubbers, condensers, purifiers, and holders, scrupulous care is exercised to prevent all escape, and in such apparatus all leakage can be quickly traced and stopped, but not so with the *retort;* here the loss is frequently unperceived, and yet so great that managers can only trace it in a high consumption of fuel, and a comparatively low average yield of gas per ton of coal which confront them in the figures of their statistical reports.

"No argument is required in the present competitive age and stage of gas manufacture to prove that anything beyond a nominal pressure in the retort entails losses by leakage, by the deposition of carbon and tar in the retorts and the ascension-pipes, by the premature precipitation of the illuminative volatile oils in passing the seals in the hydraulic mains, and in the increased expenditure of fuel required to carbonise coal in retorts internally felted with carbon. The maximum yield of gas can only be obtained by the effective application of pressure-relieving apparatus to the retorts during the important hours of carbonisation.

"The extensive use of mechanical exhausters has abundantly confirmed this proposition, notwithstanding their design and ulterior effect upon the *retort* (that of increasing its duty and durability) are largely neutralised by the constant interposition of a wasteful seal which frequently gives twenty times the pressure which economical production demands, and which ample experience proves should be wholly inoperative 23½ hours out of 24.

"The action and effect of the exhauster has not been sufficiently traced and observed beyond the hydraulic main; its chief function and value, however, centres in the *retort,* and it is of much more importance to know with certainty that a minimum pressure exists there than at any other point, because a wasteful pressure of several inches may exist in the *retort,* especially where the seals are deep, the tar stiff, and the surface liquor almost wholly drawn off (and a large escape of gas must inevitably take place under such conditions), notwithstanding the gauge may indicate no pressure in the hydraulic main. It is increasingly a matter of intrinsic importance that as much as possible of the saleable products of carbonisation (of whatever kind) shall be secured, stored, and sold. On the other hand, all waste and loss of gas at the retort means a proportionate loss of every other valuable constituent; while, therefore, every manager aims to pass a maximum quantity of gas through the meter, he must also guard himself against the incalculable loss of gas, which, under excessive pressure, passes through porous and defective retorts into the furnace, and thence through the chimney into the atmosphere, where no register can be kept. The uniform issue of numerous experiments and of established practice in several large works, extending over a period of several years, is to demonstrate conclusively that several important economical advantages accrue from the maintenance of a nominal pressure in the retorts during the hours of carbonisation; hence it becomes necessary to employ some definite means to seal the retort while charging, and to unseal it while carbonising the charge; such means are now available in the simple and durable arrangement known as Holman's Non-pressure Valvular Seal-pipes.

"The practical conclusion deduced and verified by protracted scientific investigation, has been thus recorded:—'Such volatile fluids as constitute, and are contained in crude carburetted hydrogen gas, should not be subjected to more than a slight pressure in the *retort,* or in any of the carbonising plant in immediate connection therewith, such conditions (as far as practicable) should exist only in gas-tight apparatus.'"

So far we have traced the gas from the retort, where it is generated, to the condenser, where its excessive temperature is reduced, and a large portion of tar deposited; to the scrubbers and washers, removing much ammonia and tar that have escaped the preceding operations; and last, to the exhauster, which draws the gas through from the retorts, passing it on to the next operation—that of purifying, yet to be described.

We have already named some of the many impurities of gas that should be removed before it enters the gas-holders, or arrives at the burners of the consumer. By the processes already described, it may be considered that, as far as practical means can effect, most of the ammonia and tar have been separated from the gas. But still it will contain carbonic acid and sulphuretted hydrogen, together with a greater or less proportion of bisulphide of carbon; all of which have been named, and tests suggested for their presence, at a previous page.

The purifier is intended to remove the two first of these; and many ingenious plans have been suggested, for the purpose of, at least, eliminating the sulphuretted hydrogen. This consists, or is composed, of an equivalent each of sulphur and hydrogen; and the removal of the sulphur from the sulphuretted hydrogen is the principle on which all the processes that have been proposed are based.

Until a comparatively recent day, lime was universally employed for the purification of coal-gas from sulphuretted hydrogen. That earth has a great attraction for the sulphur and hydrogen, with which it forms a hydro-sulphide.

The usual method is to pass the gas into a vessel in which lime mixed with water is kept in constant agitation. The gas is thus kept continually in contact with a lime surface, and gradually becomes purified, to a certain extent, from the sulphuretted hydrogen. The lime also absorbs the carbonic acid present, forming common chalk, or carbonate of lime. Such an arrangement is called a wet-lime purifier; but the lime is also used in a dry or slaked state.

The product that results from this operation is, perhaps, characterised by the vilest stench of any known compound; and in the gas-works where lime is used, forms a just ground of complaint for the unhealthy and even poisonous exhalations it spreads over the adjacent neighbourhood. Of course, when the lime becomes saturated with the sulphuretted hydrogen it must be removed; and it is at this period that the offensive nature of the new product becomes powerfully evident. At one time it was sold to farmers as a manure; and, containing many of the essential constituents of plants, together with its low price, from the anxiety of the gas manufacturer to get rid of it, a market was generally available. The removal, however, from the premises became an intolerable nuisance; so that, at last, the companies determined to avail themselves of the spare heat at the bottom of the furnaces to evaporate the liquid portion, by which the smell was carried up the gas-house chimney, and a great nuisance obviated.

Hydrosulphuric acid, or sulphuretted hydrogen, however, can be decomposed by other metallic oxides. Indeed, in the laboratory it is of the utmost importance in analysis as a precipitant of the chief portion of the metals as sulphides; its properties of so precipitating some, and not others, and also of affording such precipitates, generally insoluble, and of various colours, make it one of the most characteristic tests of the chemist, either alone or in union with ammonia; hence called hydrosulphate of ammonia or sulphide of ammonium.

It thus occurred that the use of an oxide might be employed to the purification of gas; and the cheapest, and, practically, the most effective for such a purpose, is that of iron. But numerous patents have been taken out for the use of salts of lead; of copper and lead together, as the acetate and sulphate; oxychloride of antimony; sulphate of iron, common salt, and charcoal; chloride of calcium, &c., &c. As Dr. Letheby observes—"Indeed, it would appear as if all the refuse matter of the arts had been successively tried and patented, in the hope of their becoming a means of extracting the impurities of coal-gas."

According to some authorities, although the use of iron had long been previously known, it was not practically applied, on the large scale, by any one until introduced for that purpose by Mr. Hills, of Deptford, who patented the method in 1849; and, since that time, its advantages have become acknowledged by its almost universal adoption by gas companies.

To manufacture the oxide of iron direct from any of the salts of that metal, would be far too expensive a process; independently of which, it would be produced as a powder—a form in which it could not be applied, because the particles would lay too close together to allow of the passage of the gas between them. Mr. Hills, however, manufactured and sold much under his patent; but so modified the condition of the oxide, as to overcome the objections just suggested. Very recently, the native sesquioxide of iron, procured from various districts, has been largely adopted. Even cast-iron borings answer the same purpose, mixed with a little sulphate of iron.

The purifiers are very simple arrangements, being rectangular vessels, in which the oxide is arranged in successive layers over each other. The gas is allowed to enter the bottom of the vessel, and gradually finds its way through the moistened oxide placed on iron trays or gratings. But as these are constantly acted upon by the newly-formed compounds, wood and other materials have been occasionally substituted. By an arrangement of valves, the gas is passed successively through two or three of these purifiers before its final exit to the gas-holder; for the publicly-appointed gas inspectors make the amount of sulphur detected in the gas a special matter of adverse report against the gas companies. The extent of purification from sulphuretted hydrogen is easily tested by the means already mentioned—the acetate of lead solution on paper, as already described, which, if it undergo no change, indicates a complete removal of the objectionable compound.

The use of oxide of iron would entail a great expense on gas companies, if, after a single employment, it became of no further avail; but the sulphide of iron, formed during the process of purification just described, has the singular but long-known property of reproducing the oxide. Removed from the purifier when no longer of value, it is exposed to the action of air and moisture, being spread in thin layers in any exposed position. After a time, the atmospheric oxygen re-oxidises the iron, simultaneously precipitating the sulphur. On the large scale, this process has long been noticed as going on in the Isle of Sheppey, at the mouth of the Thames, where an immense quantity of iron pyrites—the same sulphide of iron as is produced in gas purification—abounds. In both cases the oxidation produces the sesquioxide of iron; and in the operation of the gas-house, the spent material can thus be used repeatedly for the same purpose. Occasionally, the oxidation goes on so rapidly as to produce great heat, and even to inflame the mass. A similar occurrence on board ships laden with coal containing much iron pyrites has been a frequent cause of the destruction of the vessels by fire; for the oxidating influence of the air and moisture on the coals so stored together, and aided by an entire want of ventilation, presents all the circumstances that conspire to produce such results.

By simply turning off the gas from a purifier, and allowing a current of air to pass through the layers of oxide it contains, this oxidating

process may be effected in them without removing the oxide, which, of course, saves much trouble and expense. The top of the purifier is always closed by a movable lid, kept tight by a water-joint; and on this lid being lifted off, the process of oxidation goes on. There is, however, always a risk, and frequently the occurrence, of spontaneous combustion, from causes just described; and therefore, at present, this method is by no means of universal adoption. Besides, both iron and wood trays or sieves are, in all cases, rapidly acted on by the ordinary purifying process; and when it is attempted to convert the sulphide into oxide again, inside the purifiers, the destruction is exceedingly rapid. As the oxide is thus repeatedly reproduced from the sulphide, the sulphur rapidly increases in quantity until it will amount to one-half of the weight of the mass.

By the method thus explained, it is supposed that all the impurities of gas that can practically be removed on the large scale, according to our present knowledge of chemistry, have been eliminated, although, as already pointed out, this result is never arrived at to perfection, and, in many cases, much below what ordinary care and prudential management permit. We now pass from all chemical considerations, and have only to notice two points—the measuring of the gas by the gas-house meter, and its storage in the gas-holder, or gasometer.

In certain London gas-works, the amount of gas that passes from the purifiers is measured by what is called the station-meter, which is a meter of great size, made on the same principle as those in use by the consumer, but on a much larger scale. In places where the meter is used, its indications are carefully watched; for, to a certain extent, it acts like a telegraph, by showing speedily any increase and decrease in the consumption of gas.

It will at once occur to our readers, that the amount of gas in use, at different periods of the day, must greatly vary. Thus, in summer-time, from four in the morning to dusk, the consumption will be both small and uniform. But, as twilight comes on, all the gas-lights in ordinary use in houses, shops, warehouses, the streets, theatres, churches, &c., are simultaneously lighted, and, almost instantly, an enormous demand on the gas in the holders is made. This, of course, must instantly decrease the pressure in the mains, as existing at the moment of this sudden increase of consumption commencing. Consequently, the pressure at the gas-house must be increased, which is done by opening, to a sufficient extent, valves that supply the gas to the main, and so allowing it to press with increased force on what gas they already contain. "In order that the gas may be propelled through the main from the factory to the remotest points supplied from the works, it is necessary to give the gas a pressure or elastic force greater than that of the atmosphere. If this pressure be too small, the lights at remote places would burn much too faintly; if too large, the flames would become so strong as to consume an inordinate quantity of gas: if the gas flowed from the gas-meters, at an hour before dusk, with the same rate as at an hour after dusk, the utmost confusion and irregularity would occur. To obviate these evils is the object of the pressure apparatus. Around the valve-room are placed valves connected with each great main. There are six mains branching out of the factory, in as many different directions, for the supply of different parts of the town; and as each main requires a supply of gas proportionate to the nature and extent of the district through which it passes, a pressure apparatus is attached to it, distinct from the rest. Directing our attention to one main only, we may state, that after the gas leaves the gasometers, and enters the main, it is placed in communication with a small tube leading to a pressure-indicator, by which the exact pressure, at any time of the day or night, is determined. So long as the pressure is such as is required, no changes are made; but when it is either too great or too small, recourse is had to a valve whose interior apparatus is in connection with the main. If the pressure be too great, the valve is drawn partly across the main, by which the supply of gas is slackened; if too small, the valve is opened more than before, to admit a greater volume of gas. These adjustments are, as was before observed, made in the valve-room, every main having its own pressure-indicator, and its own valve.

"A room adjacent to the one just mentioned, and called the meter-room, exhibits to view a cast-iron case of a very tasteful kind. This case is probably about ten feet square, and seven or eight feet high, occupying the centre of the room. On the front and back are six or eight small dials, like clock-faces; and at the back are two pipes, ascending through the floor, and entering the case. The case is decorated with much elegance; and the motto, '*Ex fumo dare lucem*,' expresses, not inappropriately, the light-giving object of the whole establishment. All the gas made at the works passes through this case, or meter, by one of the pipes just spoken of, and leaves it by the other. The meter will contain a certain known quantity of gas; and while this quantity is passing through the machine, an index-hand is caused, by mechanism within the case, to revolve once round a dial-plate. Every ten revolutions of this hand cause another index to revolve once round another dial-plate; ten of these latter revolutions cause one revolution of a third index; and so on through six successive stages, the last index revolving only once while a million cubic feet are passing through the meter. The superintendent, by looking at the indications on these six dial-faces, is thus able to tell, even to a single foot, how much gas has passed through the meter to the main pipes. There are two other dials on the front of the meter, one of which is a regular clock, and the other an ingenious arrangement for showing the rate at which the gas is passing through the meter at any particular time."

The preceding quotation gives a description of the pressure and measuring apparatus belonging to one of the leading London gas-houses.

As already stated, the meter is not always employed in the gas-house; the rise and fall of the gas-holder being considered a sufficient indication, not only for estimating the quantity of gas made, but also of the amount of gas consumed at any particular period. Fig. 420 represents one of the station-meters above described.

At first sight, it would appear that such a meter as we have described is essential to the proper conduct of the business of gas-making; but, practically, such is not the case. In the first place, no meter, large or small, can be absolutely and constantly depended on for regular and exact registration. Next, as we have shown at previous pages, the variation of atmospheric temperature and pressure considerably affect the bulk of the gas, and, consequently, of its measurement. For example, if the temperature in the gas-house meter, of the gas, be one degree Fahrenheit higher than in the pipe, the meter will register 1,002 cubic feet for every 1,000 in the main. So on, in round numbers, every degree of temperature different between the gas in the meter and that in the mains, will be registered $\frac{1}{500}$th part too much or too little, according to each degree of variation—an amount a trifle too high for the exact expansion due to each degree of elevation of temperature, but still quite near enough to illustrate our meaning. Now, it is highly possible that as much as 10°, 20°, or even 30° of difference in temperature may occur, in summer-time, between that of the gas stored in the gas-holder, erected in the open air, and exposed to the fierce rays of the sun, and that of the gas as it passes through the cold pipes in the earth. Indeed, on the day that these lines are being penned, a piece of black iron-work, such as the gas-holder is made of, has a temperature of 125°; whilst the earth, at a depth far less than the gas mains are fixed, indicates a temperature less than 50°; or the total difference between the exterior of the gasometer and of the pipe of the main would not be less than 75°. It is true the gas inside the holder would not attain a heat of 125°; but as, in the shade, the present register of atmospheric temperature is about 80°, a difference would exist between the temperature of gas at this moment measured through the meter, and as in the mains at some distance from the works, of 30°. Taking now the estimate, in round numbers, of the expansion for each degree Fah., already given, there would be $\frac{30}{500}$ more gas registered by the meter at the gas-works than would be registered by another meter affixed to the main, say at a mile from the works, at which distance the gas would be considerably cooled down—of course leaving out all question of leakage, supposed to be entirely absent, and the measurement to be effected on the exact amount of gas that left the works-meter. The practical result would be, that all the gas sent, under such circumstances, from the gas-house meter, would register 60 cubic feet more per

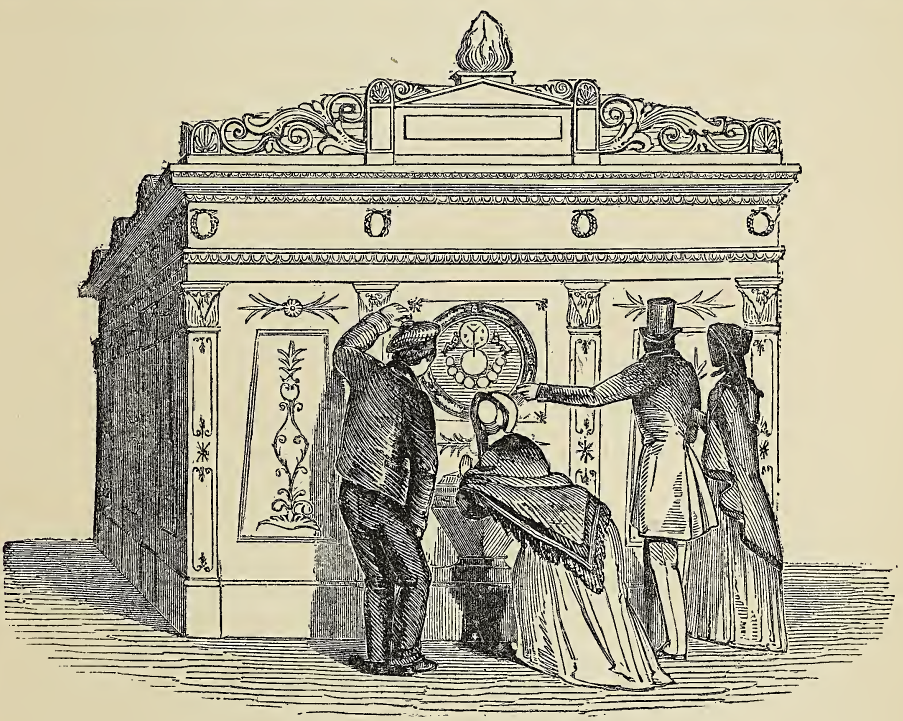


Fig. 420.—Large Station Gas-meter.

thousand than would reach the distant point, the gas being contracted, during its passage, by the cooling power of the iron pipes and the surrounding earth.

But we have supposed that the gas passes from the holders to the meter; but this is not usually the case, for it is generally passed through the meters on its passage to the holders. The temperature is, of course, high, and exceedingly variable under such circumstances; and, consequently, the value of the meter-registration is, in proportion, lessened.

We next proceed to describe the gas-holders, or gasometers, used for storing the gas preparatory to its being diffused through the mains, to supply consumers.

The principle on which all gas-holders, or gasometers, are constructed is very simple, and may be thus illustrated:—If a common glass tumbler be inverted, and placed in a basin of water, the air enclosed by it cannot escape, because the water separates the internal from the external air. If the tumbler be pressed down in the water, still, because the vessel is closed at the top, and the water acts as just stated at the bottom, no air can either escape or enter, but that already in the glass will undergo compression; that is, owing to the depth the glass is pressed into the water, the upward pressure of this fluid will cause it to enter the glass to a small distance, where, of course, it must take the place of the air previously there, and which is, consequently, pressed into a smaller bulk.

But if a piece of tube be bent syphon-form, and one leg be introduced under the rim of the glass still in water, whilst the other leg is open to the air, on pressing down the glass vessel, the air it contains will at once escape; and if it is forced down so that its top be level with the surface of the water, all the air it contains will be driven out, and water alone will occupy the interior of the glass.

The mouth being applied to the tube, air may be blown in; and if the glass be only just steadied by the hand, it will rise of itself as the air re-fills it; and so it may be emptied and filled, by repetition of the preceding plan, as often as may be desired.

This is precisely the action of the gasometer, or gas-holder, of the gas-works. The gas-holder itself corresponds to the glass tumbler; the basin to the tank; the syphon to the supply and exit-pipes of the vessel storing the gas at the works.

Two forms of gas-holders have been chiefly—we may say solely—used. In the gas-works where the production is small, only a moderate-sized gasometer is requisite; and in such cases the weight of the holder is too much for the buoyancy of the gas, and, consequently, must be counterpoised; in large gas-holders, however, instead of a counterpoise for the weight of the holder being required, its weight is too little to force the gas out, and additional weights have to be added, generally on the top, to cause the descent of the holder in the tank. It must be remembered that the specific gravity of coal-gas is much less than that of air. We have considered it as 400 to 412, compared to air=1,000; or, in other words, it would require about $2\frac{1}{2}$ times as much coal-gas as air to weigh the same.

It follows, from this, that when the coal-gas enters a large gasometer, it will tend to raise the holder in the air with force proportional to a difference between the relative weight of the same bulk each of gas and air. In fact, it is on this principle that a balloon rises in the air. It may weigh, for example—silk, ropes, car, and aëronauts—500 pounds when the balloon is empty of gas; but if the capacity of the balloon is such that it will hold so much gas that the total weight of gas and solid shall be less than the same bulk of common air, then the balloon and its appendages will necessarily rise in the atmosphere, because they are specifically lighter. Precisely the same result occurs in the large gas-holders; but more especially evidenced in the telescope kind, to be described.

In the following cut is represented the form of a small gasometer, requiring a counterpoise, and consisting only of a single holder. A is a tank, filled with water to the level, B. In this tank the holder, C, ascends and descends, guided by rollers, D D, on each side of the tank, but now generally placed at the exterior top of the holder. E is a counterpoise, by means of which the pressure, caused to act on the gas by the holder, C, is regulated. A chain passes over two pulleys, as seen in the cut, and its other end is attached to the top of the holder. F is the pipe by which the gas arrives from the purifiers to fill the holder, C; which, as the gas enters, rises out of the tank, A. The supply-pipe, by which the gas flows to the mains, is shown at G; and the outward progress of the gas is indicated by an arrow, as its ingress is similarly done. It will be, therefore, evident that the holder may be continually supplied by the constant production of gas from the retorts, until it is raised so high that the gas escapes at the level of the water, B. But, in practice, this never occurs; because, whilst the in-flow of gas is carried on, its out-flow to the mains also progresses, and the height to which the gasometer can rise, its general capacity, the amount of gas produced, and the supply, are all so mutually regulated as keep the machine in proper working position at all times that it is in use.

The telescope form is now universally adopted at all large gas-works; and the principle of its construction will be made evident by the following illustration, which represents one in section.

In Fig. 422, A represents the external tank, containing water up to the level, B, as in the preceding cut. C represents the lower gas-holder, over which is another, D. At E E is a water-joint, that entirely prevents access of external air either into C or D.

Now, supposing that no gas was in either C or D, they would both sink down in the tank, A, so that the lower rim of each would touch F F at the bottom of the tank; but as the gas passed into them from the purifiers by the supply-pipe, G, then D would be first to rise, just as the smaller tube of a telescope rises out of the larger one into which it slides. When D was quite

full, then the flanges at the water-joints, E E, would catch those of C, and the latter would then also rise out of the water until filled. The gas escapes by the outlet, H, into the mains, as in the precedingly illustrated gas-holder.

It will thus be seen that one tank may be made to hold, theoretically, any number of gas-holders, one working inside the other, telescope fashion; but, practically, the number is limited to two or three. By this method much space is saved in the erection of gasometers—a matter of great importance at all times, but especially in or near large towns, where the expense of ground is frequently enormous.

We have already explained how the flow of gas is regulated, together with the pressure, so far as the action of valves is concerned. At the present day, various forms of governors have been, more or less, successfully adopted; but the consideration of this will be deferred until we consider the numerous forms of gas apparatus and cause the gasometer to descend into its tank, although both supply and exit pipes were shut. It is really surprising, that in such immense constructions as are some of the London gasometers, no appreciable leakage is discoverable. It is true, the pressure used is not great—not exceeding that of five inches of water. Some years ago, requiring gasometers for experimenting with the mixed gases, we had two made, six feet in diameter, by an eminent Glasgow firm. On testing these with an air-pressure equal to about four pounds to the square inch, or about 8 feet or 96 inches of water, neither gasometer had descended any appreciable extent into its tank after two days' testing, allowing, of course, for variations in atmospheric pressure and temperature, which, as we have already pointed out, influence enormously the bulk of gas in the gas-holders; regulated, however, in practice, by the gas sent in and withdrawn from them.

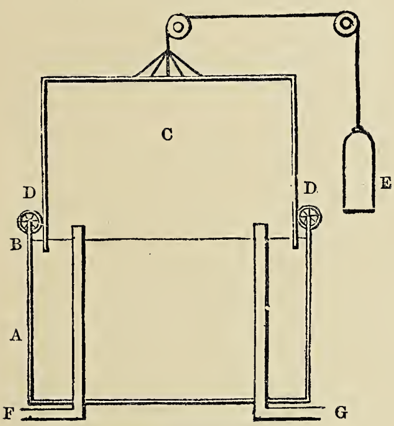


Fig. 421.—Gasometer.

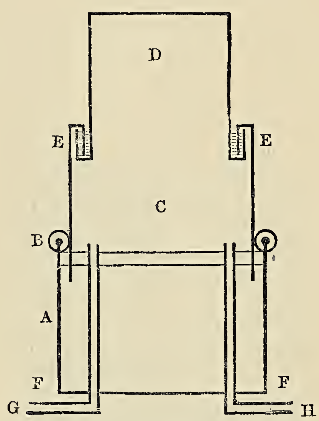


Fig. 422.—The Telescope Gasometer.

required, and in use, external to the gas-house—such as burners, meters, &c.

The material of which a gas-holder, or gasometer, is made, is invariably wrought-iron in the form of plate. The joints of each plate are made by rivets; but to make them water-tight, strands of whipcord are placed round them on each side, and coated with a mixture of red lead and oil. When the rivets are hammered home, this plan prevents the possibility of escape of gas from the joints, unless the holder is subjected to accidental external violence, when, of course, a plate may be started; and it becomes useless until repaired. The exterior of the holder is also covered, successively, with two coats of red lead, mixed with boiled linseed oil, which, penetrating all the little seams, still further add to the air-tight character of the holder. It is usual to test the soundness of the gasometer, before using it, by admitting air, which would, of course, escape through any hole that existed,

The exterior tank, in which the gas-holders rise and fall, is not necessarily required to be made of iron. In many instances, indeed, it has been made by excavating solid rock. Brick and stone are the most frequently used materials; and tanks of this form may be considered as wells of great diameter, but of moderate depth. At the Hackney-road station of the Imperial Gas Company, there is a tank 41 feet 6 inches deep, and 204 feet in diameter. In its construction, 2,000,000 bricks and 5,000 feet of stone were consumed—the site being a pond. But this size is exceeded in many gas-works, as, for example, those of the Gas-light and Coke Company at Beckton, near London. It is only necessary that the wall of the tank should be of the greatest depth, for there the holders rise and fall; all from these to the interior may be left of a considerable height, in solid ground or otherwise—a method that greatly lessens the quantity of water required to fill the

tank, and also diminishes the danger that is always incurred when large quantities of water are thus collected; for a leak at the side might cause serious consequences, similar to those that have frequently occurred from the breaking of canal and reservoir banks.

In respect to the shape of gasometers, they are always made circular, because the circle is that geometrical form which incloses most space with least periphery or external surface; and when a large gasometer is constructed, the expense becomes serious—running, in fact, from £10,000 to £20,000, or even more, for those of the largest size. As regards the size of gas-holders we cannot give any particulars, as they are constantly being constructed of greater cubic capacity as the consumption of gas increases. The largest in existence, we believe, are those at Beckton, already alluded to, from which a large proportion of London, north of the Thames, is supplied.

External to the gas-holder, and between them and the main, self-acting governors are placed. In principle, these act and are made similar to

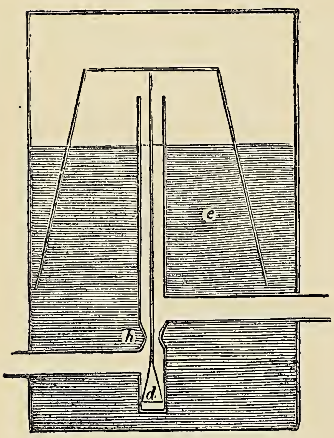


Fig. 423.—The Gas-governor.

the holders used for storing the gas. But the holder in the governor is so arranged, that, as it rises by increase of pressure, it moves a conical valve that shuts off a portion of the aperture of the pipe admitting the gas. One form of these governors (others of which, for ordinary house use, &c., will be afterwards described) is represented in the preceding cut. The gas enters by one horizontal passage, and escapes by the other, passing through the narrow tube h. Water, as shown at e, floats a holder overhead, represented in section in the cut; and as this rises, the conical valve d, at the bottom of the central and vertical tube, is also raised, diminishing the opening of the tube at h, through which the efflux of the gas from the holder to the main must take place. By thus partially closing the aperture, the pressure of the gas in the main is made self-acting. As the pressure in the governor diminishes again, the holder in it falls, and consequently the valve d descends, and so increases the aperture previously diminished by its rise; consequently a diminished pressure in the main is thereby raised to the proper average. We have already noticed the arrangements in the interior of the gas-house, for regulating the efflux of gas. These require constant attention; but the governor, as we have just seen, is self-acting, and, consequently, serves as a check on the methods previously explained; and in the absence of attention thereto, or accident, is of much importance in regulating the external pressure in the mains.

In respect to the gas-mains proceeding from the works, and distributing the gas, little need be said. As all our readers are aware, they consist of cast-iron pipes, of diameters varying according to the extent and requirements of the district in which they are laid, running from two or three inches in bore to thirty-six inches—the latter only, however, deserving properly the name of main, as the smaller bore kind can only be considered as subsidiary to, or branches of, the former. At one end of these pipes a socket is cast, which forms part and end of the pipe; whilst the other extremity is plain, and is intended to fit into the socket of an adjacent pipe. The joints are made tight after the pipes are adjusted to a proper level, and inserted into each other by first caulking, as carefully as possible, with yarn; and on to this is run melted lead, which, on becoming solid, is driven in by means of a blunt caulking-iron or cold chisel. The softness of this metal permits of its being forced in so effectually as to make a tight joint. Yet it need scarcely be remarked, that two metals of unequal expansion, in regard to heat, like lead and iron, cannot long form a tight joint; and, consequently, after some time leakage is sure to occur. But there is also another cause of the breaking of a joint. No matter how carefully the pipes may be laid and fixed in the first instance, the earth beneath them eventually subsides, and consequently the horizontal position of the pipe becomes affected, and the joint of each socket loosened. This of course will cause an escape of gas—a loss to the company, besides producing an offensive and unhealthy smell. Occasionally serious and fatal explosions have been brought about by this cause. The gas, escaping from a leaky pipe, gradually finds its way through the earth, and enters, perhaps, a cellar or the basement of a house. A smell of gas is at last perceived, and some careless persons enter to find out the cause with a light. By the flame of this the mixture of coal-gas and air is ignited, and most lamentable results hence occur to both life and property. A few years ago three or four streets were completely wrecked in the neighbourhood of Tottenham-court-road, London, from this cause.

Generally speaking, even the large mains are comparatively thin. A 36-inch one is generally not more than three-quarters of an inch thick at the socket; one of 24 inches in diameter does not exceed half an inch thick. They need no strength, however, greater than sufficient to stand their own weight, so far as the pressure of

the gas is concerned; for while water-pipes are sometimes required to stand a pressure of from 50 to 100 pounds, or even more, on the square inch, the gas main never is required to withstand more than would be afforded by a column of water five or six inches high, or not more than three or four ounces per square inch of internal surface. Of course it is a matter of great importance to the gas company to minimise, as much as possible, the amount of money lying dead in the mains and branch pipes—items of very serious cost in all cases. In regard to iron gas-pipes, they are rendered useless for any other purpose except that of re-laying for gas, or for breaking up as old iron, on account of the deterioration they suffer from the action of ammonia, &c.; and also owing to the abominably stinking products they are made the receptacles of, and which could not be entirely removed without exposing them to a red heat, the cost of which, and the possible fracture during the operation, rendering such a method out of the question.

The great loss sustained by the gas companies through leakage by the pipes has been already referred to at p. 576, *ante*, and there stated to be averaged at about one-sixth of the amount produced in the works. But higher estimates have been, with much reason, suggested; and even 20 per cent., or one-fifth, has been considered as not too high for the amount of this loss.

Having now examined all the mechanical, engineering, and other leading details of the gas-house, we may make a few observations on the total amount of gas that may be expected from ordinary good gas-coal, as now employed in London.

The generally received opinion of the gas value of the coal usually employed is, that each ton should yield, on an average, 9,500 to 10,000 cubic feet of gas. But two circumstances influence the amount produced. If the coal be heated too long in the retort, more gas than usual may be obtained from the same coal, yielding, as just stated, 9,500 cubic feet. The usual time in which the coal is in the retort is six hours. But if this period be increased, gas of a very much inferior illuminating power is given off; and, consequently, those portions that were first produced become deteriorated by dilution of the inferior illuminating gas, although the quantity is increased. Of course, the richer the coal, the greater is the quantity of gas that may be obtained from it; and a superintendent of considerable gas-works, in a part of Scotland, supplied with Lesmahago cannel, states that he has run up the production to 11,500 cubic feet per ton. The Lesmahago coal, however, is one of the richest of all ordinary gas-coal, and so a high standard of gas production, both in quality and quantity, may be obtained from it. In respect to quality, twenty-six candles (see *ante*, p. 566, for explanation of this term) is by no means an unusual average.

According to some careful experiments made by Messrs. Barlow and Wright, the following is the production of each specimen of coal named per ton:—

Coal.	Gas in cubic feet.
Boghead	13,340
Wigan cannel	10,850
Lesmahago do.	10,779
Wemyss do.	10,584
Newcastle do.	9,830
Pelton main	9,650
Derbyshire deep main	9,400
Ramsay cannel	9,016
Luchgelly ditto	8,381

This table indicates a vast difference in the gas-producing powers of the different kinds of coal named, amounting to between 50 and 60 per cent. At the same time, the general reader will be enabled to judge of the cause that makes the supply of gas in Manchester, Wigan, and adjacent towns, and also the middle and south of Scotland, generally so much higher in quality than that obtained in London. All the places above named get the gas from rich cannel, mostly dug up either beneath the very town where it is to be employed in gas-making, or else but a few miles distant. Now the shortest distance of London from any of the best cannel districts (Wigan) is about 200 miles, which has to be traversed by the highly expensive methods of either railway or canal transit, that greatly exceed in cost the carriage of coals from Newcastle by sea, especially since steam colliers have been put on the service, and the delay caused by opposite winds, calms, storms, &c., has been, to a large extent, obviated.

The amount of coke obtained from various qualities or kinds of coal greatly varies. Of all kinds, Boghead, which is richest in hydrocarbon, is least so in the production of coke.

The following table exhibits the relative coke-giving qualities of some of the coals already named as of constant use for gas-making. We have chosen what may be considered as an average of the varieties employed.

Coal.	Coke in lbs.
Pelton main	1,543
Ramsay cannel	1,435
Newcastle do.	1,426
Derbyshire deep main	1,335
Wigan	1,332
Luchgelly cannel	1,245
Wemyss	1,156
Lesmahago	1,077
Boghead	715

Here, just as in the proportion of hydrocarbons, great difference of quality in respect to coke production is evident. Leaving out Boghead, which contains so much ash as to remove it almost from the category of coal on that account, although justly entitled to it on others, we notice that Lesmahago, one of the richest cannels, is the poorest in affording coke. On the other hand, the Luchgelly cannel, which is the poorest in hydrocarbons (see preceding table of these, at p. 572), affords most coke.

From these facts, it is evident that if circumstances universally permitted, a judicious admixture of various qualities of coal would, in every sense, be of most value to the gas-maker. The excess of hydrocarbons in one, and

the abundant product of coke by the other, would thus make a kind of general average, that would benefit, not only the gas companies, but also the public; for the former would reap an increase of profits, and the latter could obtain a better candle value of the gas, even at the prices now charged.

In many cases such a plan is adopted. Thus Boghead coal is distilled in one retort, whilst Newcastle coal is distilled in another, the gases entering the same hydraulic main, and passing on through all the stages of the manufacture to the gas-holder, thence to be sent out for combined burning. But owing to the distance that London is from all the cannel centres—200 miles in the Wigan direction, and more than 400 from the Lesmahago and Boghead fields—the expense of carriage to the metropolis, and the great demand for those rich coals, and consequent high price, forbid their extensive use.

We may here conveniently notice the present state of the London Gas Companies as illustrating the progress that has been made since the first attempt at using gas as an illuminating agent, the history of which is fully detailed in the Introduction to this work.

At the close of 1880, the number of London Gas Companies had been reduced to six by the amalgamation of smaller companies with those of larger extent. Of these the Gas-Light and Coke Company possessed a capital of about £9,000,000. They made about 6,000,000 thousands of cubic feet in the half-year, or in round numbers 12,000,000 thousand cubic feet for the year. The total amount of coal carbonised in the year was about 1,200,000 tons. The residual products which will shortly be fully dealt with amounted to about 1,400,000 chaldrons of coals, about 13,000,000 gallons of tar, and nearly 350,000 butts of 108 gallons each of ammoniacal liquor. The total revenue amounted to about £1,800,000 per annum. The South Metropolitan Gas Company had a capital of about £1,000,000, a revenue of £350,000, and made about 1,800,000 thousands of cubic feet, using during the year about 190,000 tons of coals. The Commercial Gas Company had a capital of about £700,000, a revenue of about £300,000, used 160,000 tons of coals, and made about 1,600,000 thousands cubic feet of gas. The London Gas-Light Company had a capital of about £850,000, a revenue of £311,000, used about 155,000 tons of coals, and made 1,529,833 thousands of cubic feet of gas. The Phœnix Company had a capital of £1,210,000, had a revenue of about £400,000, made about 2,000,000 thousands of cubic feet, and used about 200,000 tons of coals. The Surrey Consumers' Company was on a smaller scale.

It will thus be seen that at the present time the total amount of capital expended for lighting London alone is over £13,000,000. It is impossible to estimate the total amount of capital employed in this kingdom for gas illumination. In many provincial towns there is far more gas used in the ratio of population than in London, so much so, indeed, that to purchase an ordinary candle is a rare occurrence. In fact, gas is gradually, but surely, superseding all former methods of artificial illumination.

We shall next consider some of the residual products of the gas-house, and the uses to which they are applied; and so conclude our subject, so far as any form of coal is used to make gas, and any of the products of its distillation become of use in other manufactures.

Residual Products of Coal-Gas.

It has already been intimated, that one of the greatest discoveries of this century, is that—or rather, we should place the subject in the plural number—*those*, that have caused the utilisation of coal products, besides gas and coke, as the result of dry distillation pursued in the gas-house.

Barlow, in the *Encyclopædia of Arts, Manufactures, and Machinery* (1828), remarks—"A chaldron of coal, of average quality, will give about $1\frac{1}{4}$ to $1\frac{1}{2}$ cwt. of tar, and from 15 to 18 ale gallons of ammoniacal liquor; and as the demand for these articles is very uncertain, they often accumulate to an inconvenient extent. Under these circumstances, part of the tar is usually employed as fuel in the retort-house; and in some of the gas-works, the ammoniacal liquor is manufactured into sal-ammoniac, and other saleable forms of this alkali" (ammonia).

Indeed, it is only of recent years that the valuable substances produced by the dry distillation of coal have been properly esteemed; and still more recent is it that those properties have been turned to practical account. In 1825, Faraday was the first to obtain benzine from coal; and yet, as just quoted from Barlow, this benzine, or benzole, was utterly unknown as a product of commercial value. In the following year to the discovery by Faraday of benzole, Unverdorben discovered aniline; that is, in 1826. Subsequently, Dr. A. W. Hofman, well known to English chemists, found aniline as a product of coal-tar; and thus, little by little, the riches of coal became developed.

It will be impossible for us here to trace out the entire history of the various substances that result from the dry distillation of coal. They are too numerous—and, further, it would be needful to enter into extensive expositions of certain chemical doctrines, as those of "series," "substitutions," &c.—to do the subject justice. Suffice it to say, that by distilling coal, a great variety of hydrocarbons is formed beyond those employed for illuminating purposes. In the practical operation of gas-making, all these are detained in the water of the hydraulic main; and it has not yet been attempted to utilise them in the gas-house, except so far as the ammonia has been, and frequently is, extracted by a separate manufacture, already described at p. 643, *ante*. We shall briefly detail the most important products derived from the residua of the hydraulic main.

The amount of ammonia and tar (the most readily available sources of profit, to the gas companies, of all the residual products of gas manufacture) greatly varies, like the hydrocar-

bonous illuminating gases and coke, tables of which, as produced from certain kinds of coal, have been already given. On an average, in respect to the manufacture of coal-gas in London, where Newcastle coals are largely used, it is found that a ton of coals will yield ten gallons each of tar and ammoniacal liquor. But the proportion of each greatly varies according to the quality and general character of coal employed. This arises, in respect to the ammonia, from the variable amount of nitrogen present. Thus, while Luchgelly cannel yields 340 pounds of ammoniacal liquor per ton, Boghead coal, so rich in hydrocarbons, but destitute of nitrogen, yields none. Generally all the Scotch gas-coal is deficient of nitrogen; therefore, as stated at p. 583, *ante*, we have usually failed to obtain any sensible amount of ammonia when testing its gas for that alkali.

According to Messrs. Barlow and Wright, the coals named in the subjoined table, produce the quantities of tar and ammonia there set down. These hydrocarbonous, illuminating, and coke products, have already been noted at pp. 597 and 598, *ante*.

In giving the table, however, it must be remembered that any such statements as it contains are not to be relied on for general accuracy in respect to the individual production of each kind of coal; for nothing is more difficult, in any branch of mineral analysis, than to find specimens of substances the analysis of which can be relied on as invariably indicative of the qualities or properties of the bulk from which they are obtained. Thus, in agricultural analysis, it is impossible to select specimens of ground that shall afford proper data for estimating the value of a soil even of a field, except comparatively—still less of an estate. Hence the varying productive powers in the same property, if extensive, as regards the area of land it embraces. The amount stated is the product in pounds from a ton of coal.

Coal.	Tar.	Ammoniacal Liquor.
	lbs.	lbs.
Boghead	733	0
Lesmahago	598	$4\frac{1}{2}$
Ramsay cannel . . .	295	$6\frac{3}{4}$
Wigan	248	162
Luchgelly cannel . . .	225	340
Derbyshire deep main .	219	179
Wemyss	210	trifling.
Pelton main	102	102
Newcastle cannel . . .	98	60

Generally, in the preceding, we notice that the production of tar is inverse to that of ammonia. In the table the tar has ruled the order of the amounts stated in decrease. Referring to the tables at pp. 597 and 598, *ante*, it will be seen that generally, however, there seems no necessary connection between the amount of coke, tar, and ammoniacal liquor as afforded by coal distillation—a fact that indicates the presence of nitrogen in coal to be more accidental than constitutional.

Whatever theoretical value may be attached to the presence of nitrogen in coal, its practical importance is simply derived from the production of ammonia, and certain compounds of cyanogen, but especially of the latter—Prussian blue. At p. 584, *ante*, we have generally stated the commercial value of the nitrogen as united with hydrogen to form ammonia, and resulting either as sulphate of ammonia and sal-ammoniac, when properly prepared. A ton of Newcastle coals will produce about seven or eight pounds of Prussian blue, by the production of cyanogen, a carbide of nitrogen (or union of nitrogen with carbon), that unites with iron in the oxide employed in the various modes of purification, already detailed.

The tar, separated from the ammoniacal liquor, yields up the most important chemical substances producible by the dry distillation of coal, primarily as fluid bodies; resolvable, however, into a great variety of forms and combinations.

Tar, as is well known, is a dark, thick, black-looking fluid, possessing an odour offensive to the highest degree. On distillation, it affords, successively, an astonishing variety of products. First we may notice a mineral naphtha, that has been much employed for illuminating purposes, and to which further notice will be given. At the same time, creosote and carbolic acid, both valuable antiseptics—and hence largely used for preserving sleepers for railways, palings, posts, wooden ships' bottoms, ropes, and most vegetable matter—are obtained. These are separated by condensation after distillation of the tar in iron retorts has been carried on. The uses of tar, in this respect, are therefore evidently of great importance in connection with many branches of manufactures and trade.

Chemically, however, the secondary products of tar distillation are the most interesting. They chiefly consist of a series of hydrocarbons, in which the hydrogen and carbon are united in successively increasing proportions; the equivalents of each respectively increasing by two; any formula, as $C_{12} H_6$, becoming $C_{14} H_8$, $C_{18} H_{12}$, &c. Amongst such are benzole, or benzine, already named as discovered by Faraday, and also derivable from benzoic acid, a product of gum benzoin; toluole, also present in a benzoid substance, the well known tolu balsam; cumole; cymole; naphthaline, which is abundantly produced, and deposited, as a white mica-looking substance, in pipes passing from the purifiers; paraffin; and many other bodies, all characterised by a union of carbon and hydrogen.

But others are also produced, which, like ammonia, contain nitrogen; yet, unlike that alkali, possess also carbon as an essential element. They are extremely interesting, and also numerous. These, like the preceding, rise by two equivalents each in regard to their carbon and hydrogen, yet retaining only one equivalent of nitrogen in each. Commercially, only one need here be referred to as a product of gas-tar; it is *aniline*, the basis of all those beautiful colours now so largely used in dyeing and calico-printing, in place of the products of plants, as indigo, turmeric, fustic, red woods, cochineal, safflower, &c.; which they have almost completely replaced.

Paraffin and aniline are of the greatest importance, at this time, amongst all these products. The former we may dispose of for the present by deferring it to lengthened future consideration. In respect to aniline, its full consideration would more properly belong to the subjects of dyeing and calico-printing ;* but a brief *résumé* of its manufacture and uses may be here given.

The amount of aniline obtainable directly from coal-tar is too small to be of any commercial value ; but the benzine, or benzole, is readily convertible into it. Benzole is composed of carbon and hydrogen, symbolised as $C_{12} H_6$, as distilled first from coal naphtha, it being given off at a temperature of about 190°. Strong nitric acid is added to the coal product, the benzole, when a very violent action ensues. By this, nitrobenzine, or nitrobenzole, as it is indifferently called, is produced. This latter liquid has the odour of bitter-almond oil, and an analogous chemical constitution, being now largely used as a substitute for that article in perfumery—another astonishing result of applied chemistry, only equalled in its kind by the production of jargonelle pear, pine-apple, apple, strawberry, and other flavours, from rotten cheese, rancid butter, &c.

This nitrobenzine, or nitrobenzole, is converted into aniline by the following method :—One hundred parts of it are mixed with the same quantity of acetic acid, and two hundred parts of iron filings. Through the chemical action that ensues, much heat is produced ; and, eventually, the nitrobenzole, formerly composed of $C_{12} H_5$, or twelve equivalents of carbon, five of hydrogen, together with NO_4, or one of nitrogen and four of oxygen, become converted into aniline, the composition of which is $C_{12} H_7 N$, or twelve equivalents of carbon, seven of hydrogen, and one of nitrogen. The aniline is distilled in a retort from the mixture just mentioned, and passes off as a colourless fluid, of an alkaline reaction, and a specific gravity a little greater than that of water.

Although in itself colourless, it is capable of producing almost every variety of the most brilliant shades of red, yellow, and blue, by a series of chemical reactions, brought about by the action of various substances, as bichromate of potass, &c., &c., the details of which we cannot here enter into. By such actions, mauve, Magenta, aniline purple, roseine, and all the beautiful coal-tar dyes are produced, now universally employed for dyeing cotton, wool, and silk.

It is thus evident that, whilst the gas-house would seem to present the foulest and most offensive compounds, yet, by the magic aid of chemistry, such may be converted into the most useful and beautiful products. Briefly these have been described as ammonia, of so much use in medicine or pharmacy, agriculture, manufactures; naphtha, creosote, or carbolic acid, so valuable as antiseptic and disinfectant agents ; nitrobenzole, now substituted for bitter-almond oil ; aniline, the basis of coal-tar dyes ; with several other products, some of which will require more distinct description on account of their individual importance. But the chemistry of coal-tar products is yet only very imperfectly understood ; and there is little doubt that we have, at present, obtained only a fraction of the valuable products that they are capable of affording. Indeed, but a few years only have elapsed since even aniline was made of commercial use, as it was not till early in 1859 that Mr. Perkins succeeded in introducing the use of his aniline purple on the large scale.

* These will be given in a subsequent chapter.

Gas produced from other Substances than Coal.

Although, at the present day, coal only is used as a source of gas for illuminating purposes generally, many other substances have been tried, and, to some extent, used for the same object. Companies have been established to carry out the plans of ingenious inventors ; but, hitherto, no amount of success, at least as regards commercial or pecuniary prospect, has attended such attempts.

It will be evident, that all animal and vegetable substances composed of carbon and hydrogen, wholly or in part, are capable of affording gases that may be applied to illuminating purposes ; but whilst, theoretically, such sources may be had recourse to, the question of their individual economic value will not permit, in general, of their use. Thus, some years ago, it was attempted to utilise the immense extent of bog land in Ireland, and other parts of these islands, by converting the peat thus afforded into valuable products, such as paraffin, and allied substances. It has been found that, however well such attempts may succeed in the laboratory, they fail to become commercially successful.

In the early part of this century, Dr. Henry experimented on sperm oil, with the intention of using it as a source of gas ; and, subsequently, apparatus was constructed for producing oil-gas on the large scale. The method consisted of allowing a thin stream of oil to run into a tube heated red-hot, and loosely filled with fragments of coke. On the oil touching these, it was, of course, decomposed, and its hydrocarbonous gases set free. Practically this plan is almost the same as that adopted in making coal-gas, the variation of detail being, of course, necessary on account of the fluid nature of oil. Gas so produced, however, has the advantage of requiring no purification except such as may be effected by simply washing with water, by which any oil in the state of vapour, and not decomposed, is separated and saved, again to pass into the retort for destructive distillation.

The gas thus afforded has a very high illuminating power, equal to double that obtained from the best ordinary description of gas coal. It has also a high specific gravity, being from 800 to 900; air = 1000; and hence averages about double that of coal-gas, which, as we have stated, varies from 400 to 412. During its combustion it yields only carbonic acid and water. It is quite free from smell ; and, altogether, is

much preferable to the best gas afforded by coal. In respect to the quantity of gas produced, it is stated that a gallon of whale oil affords ninety cubic feet of gas; and, generally, we believe that such fatty matters as oil, tallow, kitchen-stuff, &c., yield ten times as many cubic feet of gas as they weigh in pounds avoirdupois. This amount is double that yielded by coal; for, as shown in our former pages, one ton, or 2,240 pounds, generally give only about 9,500 cubic feet of gas. On the other hand, however, coal produces coke—a substance of great value as an article of profit, at least in gas manufacturing in London.

But, in making oil-gas, a portion of the oil is entirely wasted by a certain quantity of its carbon remaining, as a fine black powder, in the retort. The amount of this loss varies for different fatty materials; but, on an average, may be reckoned as from one-third to one-half of the amount of oil or fat used. And from this arises another objection to the successful production of oil-gas; for, by the deposition of this carbon, the retort becomes choked up, and the production of gas ceases.

Under many circumstances, however, oil-gas might be well adopted. Thus, on board ship an oil-gas apparatus could be easily fitted up, which might be safely worked—a gas-holder, of small dimensions, only being needful to regulate the pressure; the supply of gas being kept continuous, and regulated in its production by means of a tap; for, according to the amount of oil allowed to flow into the retort, so would that be of the gas produced; and, by simply turning off the supply-tap, the production of gas would almost instantly cease, to be resumed when desirable. From the description of making coal-gas, occupying the preceding pages, it will be evident that such a course would be impossible with coal, which must be thrown *en masse* into a retort, and the gas produced at once collected and stored till required for use. Again, many countries produce large quantities of oil, but are destitute of coal; and there the production of oil-gas would be really cheaper than coal-gas; and it is a matter of surprise that the plan has not been adopted in such localities for general illuminating purposes. A gas-oil apparatus may be easily erected, used, and managed in large private establishments distant from any gas-works; and to supply the wants of this kind, private companies have been established; but, as a rule, have failed.

Many years ago, a company was established in London, entitled the Portable Gas-Light Company, which proposed to supply oil-gas in a compressed state. The oil-gas manufactured by them was compressed in cylindrical vessels of great strength. The last one of these we saw, some years ago, was of the form of an egg-ended cylindrical steam-boiler, about three feet long, and eight inches in diameter, having been adopted by an inventor to contain compressed air, which he was desirous of introducing as an "economical" motive power. The oil-gas was forced into these vessels until it exerted a pressure of about 300 pounds on the square inch; consequently the vessel contained twenty times its ordinary capacity for air at the usual atmospheric pressure.

The outflow of the gas for consumption was regulated by a stopcock; and, of course, the apparatus was quite portable, and might be placed in any desired position, taking up but little room. Indeed, these gas-vessels were enclosed in vases, &c., of an ornamental character; and so were not in any way detrimental to the appearance of a hall, staircase, or an apartment.

During the compression, however, a portion of the gas was converted into an oily liquid, composed of several hydrocarbons, especially one discovered by Faraday, who investigated the nature of this deposit. It was isomeric with olefiant gas, mentioned at p. 573, *ante*. Other hydrocarbons, named at p. 599, *ante*, and subject to the same law of combination as there described, constitute portions of this fluid. One-fifth of the gas was lost by this reduction to the fluid state.

If there was no other objection, however, than this, it would only be a question of expense. But the enormous pressure—twice that usually adopted as an average in locomotive boilers—that the vessel had to sustain, was a constant source of danger, that might result from the bursting of the vessel by any external injury to it, or an excessive rise in the temperature of the gas it enclosed. Independent of such considerations, the price of the gas, as thus supplied, was ten or twelve times that of coal-gas; and, for these and other reasons, portable gas companies are now only remembered as absolute failures.

In a similar way, and, at times, from other causes, attempts to produce gas on anything like a large scale, from resin, tar, petroleum, wood, peat, &c., have all failed to be of any advantage where coal can be got at a reasonable price. And as new coal-fields are now being constantly discovered in most civilised parts of the world, it seems very probable that none of these substances will, to any extent, replace that material as a source of gas for illuminating purposes.

Some ingenious, but, in a commercial point of view, vain attempts have been made to use water as a source of gas, by abstracting its oxygen, and setting the hydrogen free, adding carbon to the gas by passing it through or over some volatile hydrocarbons. Numerous modes exist by which water can be decomposed. The hydrogen gas produced, is, however, not luminous to any extent. If, however, a little ether, or several other fluids containing carbon, be poured into the bottle, and the jet be replaced, on applying a light a brilliantly luminous flame will be afforded.

On these principles several patents have been taken out for the manufacture of gas from water. One inventor proposed to pass steam over red-hot coke or charcoal, contained in a tube, and thus procure hydrogen and carbonic acid, the latter of which he absorbs by lime; whilst the hydrogen is conducted to a vessel

containing naphtha, &c., from which the non-luminous hydrogen takes up sufficient carbon to make it an illuminating agent. Others decomposed water by electricity and magnetism, so as to obtain the hydrogen, and afterwards naphthalising it. This latter plan reminds of a proposal made to us, some years ago, by a well-known public projector—quite untainted, however, with any scientific knowledge—to undertake the chemical and electrical management of a company which had for its object the working of large steam-vessels, in the boilers of which the steam was to be raised by voltaic electricity in place of coals! We found it extremely difficult to persuade him, that whilst the electrical plan would have cost not less than fifteen shillings to evaporate a wine-glassful of water, coal would do the same at an expense not to be expressed by the smallest coin of the realm. It is indeed surprising how persons ignorant of the first principles and practice of science, not only succeed in gulling themselves, but drag others into their own vortex of ruin. Every branch of applied science has thus had its stultifiers; and that of gas-making is certainly not behind the rest in affording instances of the most egregious and absurd errors of this kind.

In America, however, the manufacture of water-gas seems to have been adopted in certain cases. We are indebted to *Engineering* for the following remarks on this, and also for the illustrations given.

The production of a cheap and efficient gas for illuminating purposes, as well as for fuel, is a problem of high interest, especially in the United States, where gas manufacture is too frequently a monopoly, attended with the natural result of high price and bad quality. Of the many processes that have been suggested for accomplishing this end, one appears to be attracting considerable interest in America, and also in Sweden, where some interesting experiments have recently been conducted. This is known as the Lowe and Strong gas process, which is now being worked by the American Gas, Fuel, and Light Company, of New York. Whatever may be the ultimate development of the process, what has already been done is of sufficient importance to call for some notice. The mode of manufacturing the lighting gas is simple, and the apparatus is shown at p. 604 in Fig. 424. It consists of two brick chambers, *a* and *e*, the former being called the generator, and the latter the superheater. The two are connected by a pipe *f* passing from the top of the generator to the bottom of the superheater, which is nearly filled with loose firebrick. From the top of the superheater a pipe passes the gas, when produced, to the purifiers, the positions of which are indicated. The mode of production is as follows:—The generator is charged with anthracite, broken to a large egg size, through the opening *p* in the top, which is then closed, and the mass is fired with the aid of an air-blast under the grate, the gases passing off to the bottom of the superheater, which is formed as a combustion chamber, the roof of which is arched and perforated. Into this chamber an air-blast is also introduced, and intense combustion ensues, the gases passing through the mass of loose brickwork which are brought up to a white heat, by the time the body of coal in the generator is cherry red. The valve *h* at the top of the superheater is then closed, the blast is discontinued, and the operation of gas-making begins. Superheated steam is blown into the mass of red coals in the generator and becomes decomposed, and at the same time small streams of crude petroleum flow upon the top of the coal, evaporating and mixing with the ascending gases of the decomposed steam, and passing together to the bottom of the superheater flow upwards through the mass of white-hot brick, to be discharged into the washer. This superheating action completes the production of the gas, and at the same time arrests any small particles of carbon that may be carried over. As soon as the heat falls too low for proper admixture, the supplies of steam and hydro-carbon are stopped, a little more coal is added to the generator, the blast is again turned on, and the process is re-commenced.

The method of producing the fuel gas is somewhat different, and the apparatus is shown in Fig. 425. The generator, of which two views are given, is charged with coal or coke, and fired by a blast admitted beneath the water grate W. The ascending gases pass through an opening near the top into the first superheating chamber, which is filled with loose set firebrick; the air descending through a grating ignites the gases which pass down the first and up the second chamber, escaping through the opening Y, which can be closed by a valve. By the time the coal in the generator is red, the heating chamber is at a white heat. The air-blast is then shut off, the valve Y is closed, and steam is admitted just beneath it. This steam becoming decomposed and intensely heated, flows down the second and up the first heating chamber into the generator, when it is met at V by a shower of coal-dust ground to an impalpable powder, and fed from the hopper Z by an Archimedean screw. The coal-dust is instantly distilled on coming in contact with the gases of the decomposed steam, an intimate combination takes place, and the mixture descending through the mass of heated coal passes out into a hydraulic main.

The method of making lighting gas, as described above, appears to be successfully introduced in many American cities, in some instances on quite a large scale; amongst others we may mention Lancaster and Scranton, in Pennsylvania; Baltimore, where nearly 1,000,000 cubic feet a day are made and distributed through 55 miles of mains; Newburgh, New York; and Paterson, New Jersey. Experimental works were also established on a large scale in Philadelphia, but these failed through, it is stated, the unfair opposition of vested interests. As to the quality of gas produced, we may refer to one of several reports made by Professor H. Wurtz, of Hoboken, on the works established at Manayunk. His investigation was made on the product of one day's working, 183,000 cubic feet.

To produce this, 9,843 lbs. of anthracite, equal to 51 lbs. per 1,000 feet of gas, was used, representing a product of 441,000 feet of gas per ton (2,240 lbs.) Naphtha of a specific gravity of ·70, instead of crude petroleum, was employed to the extent of 791 gallons, or 4·1 gallons per 1,000. An illuminating power of 20·006 candles was obtained, but as the purification was imperfect, a higher standard could not be reached. The following is Dr. Wurtz's analysis of the gas :—

Sulphuretted hydrogen	·44
Carbonic acid	2·29
Oxygen	·20
Carbonic oxide	20·04
Olefiant gas	7·99
Hydrogen	69.04
	100·00

At Baltimore, where the process has been more fully developed, the same observer found a photometric value of 22 candles, with a consumption of 5 feet per hour, and no traces existed of carbonic acid, sulphuretted hydrogen, or ammonia. The extreme variations in density were less than one per cent. The cost of gas in the United States is so high that the public appears to be well pleased with charges made for the so-called water gas. Yet these are enormous. For instance, at Clyde, New York, 3 dols. per 1,000 are charged; at Kingston, Canada, 2·90 dols.; at Lancaster, Pennsylvania, 2 dols.; and at Baltimore, 1·90 dols. At this latter place, indeed, the price is higher by 40 cents than the reduced charge of the gas company, but a large number of the public appears to prefer the dearer but better light.

As regards the fuel gas it is claimed that 50,000 feet per ton of coal can be made, including the dust fed into the generator, and the fuel employed for producing the steam, which is equal to 25 or 30 per cent. of the whole. The latest information on this subject is contained in a report of the experiments conducted recently in Stockholm. In the furnaces erected there, peat powder instead of coal-dust was used with good effect. It is stated that without the use of any dust, the combustion of 43·9 lbs. of coke in the furnace produced 1,000 feet of fuel gas, and it was found that each pound of peat powder added, produced 7·8 cubic feet of gas. Comparative experiments were made with the gas from a Siemens regenerator which produced 55·12 and 14·7 cubic feet of gas from one pound of coke and peat respectively, the product per ton of fuel, including ordinary coal-gas, being as follows :—

	Feet.
Ordinary coal-gas per ton	10,000
Siemens's regenerator (coke and peat)	123,468
Water-gas	56,000

But according to one of the Swedish reporters the heating values were respectively in the proportion of 344, 174, and 55, representing a value of 22, 43, and 63 per cent. of the total heating power of the fuel; but in this comparison the value of the coke residuum from the gas produced is not taken into consideration. We give these figures as they are contained in the report, merely remarking that they are confirmed by Mr. C. A. Dellwik, Director of the Swedish Iron Masters' Association.

In respect to peat, whilst not desirous of expressing an opinion too depreciatory of its value as a gas material, as we have already done in respect to its general utilisation for the production of paraffin, &c., it certainly seems improbable, at present, that it can be used for the manufacture of gas. Quoting from an authority whom we are not exactly at liberty to name, but who is well known as one of the most active and intelligent officers of health, as an analytical chemist, and especially as chemical inspector of gas in *one* of the largest cities in Europe—this gentleman observes (*cir.* 1854), in respect to peat gas :—"Many chemists have, at different times, devoted their attention to the subject; but it is only very recently that precise information has been obtained concerning it. Sir Robert Kane, in Ireland, and Dr. Letheby, in England, have each reported on the quality of the products generated during the destructive distillation of peat; and, from these statements, it appears that 100 parts of peat will furnish from 19 to 40 parts of charcoal; from 2 to 5 of tar; from 11 to 38 of aqueous matter; and from 25 to 58 of gas. The charcoal is very valuable as a deodoriser and disinfectant; the tar is rich in paraffin and creosote; the watery fluids contain ammonia, acetic acid, and wood naphtha; and the gases consist of hydrogen, carbonic oxide, carbonic acid, and various hydrocarbons. One thousand parts of peat will yield, on an average, 2·7 of ammonia, equal to 10·4 of the sulphate of ammonia; 1·9 of acetic acid; 1·4 of wood naphtha; 7·9 of volatile oils; 5·5 of fixed oils; and 1·4 of paraffin. From Dr. Letheby's experiments, it appears that a ton of peat will furnish about 13,000 cubic feet of gas, the illuminating power of which is equal to seven standard candles, when the gas is burned from an Argand that consumes five cubic feet per hour; but the intensity of the light may be brought up to any degree by the usual process of naphthalisation. As peat is very abundant, its products valuable, and its gas entirely free from sulphur, it is very probable that it may be used with great advantage as a source of inflammable gas; in fact, a patent has been taken out by Mr. Hansor, for the manufacture of an illuminating gas from a mixture of 12 parts of peat, 12 of resin, 8 of coal-tar, and 16 of oil. This is effected by distilling the mixture from perforated iron boxes, placed in a furnace heated to cherry-red; the condensible vapours so produced are then passed through another furnace, divided by diaphragms, and raised to a bright-red heat. By this they are decomposed, and rendered permanently gaseous. The gas so obtained, after having been purified by means of lime [to remove the carbonic acid], has a density of ·626, and its illuminating power is a little higher than that of common cannel gas, or about twice as great as that of ordinary coal-gas. A fish-tail burner, consuming 2·5 cubic feet per hour, gives the light of 9·2 standard sperm

candles; and an Argand, consuming 3·5 feet, gives the light of 15·5 candles."

The preceding quotation, giving opinions expressed above twenty-five years ago, has hitherto not been verified by any practical result; and, as far as we have seen and examined peat, in Scotland and Ireland, we can only express an opinion, that its value has, in the remarks just quoted, been far too highly rated: in fact, like many other conclusions arrived at in the laboratory, it has failed when tested on the large scale. One great objection to the use of peat, for any purpose requiring destructive distillation, is the great amount of water it contains. The traveller in any peat country can easily perceive this by mere inspection of the places whence it is collected. According to the preceding authority, the articles examined by him varied, in the quantity of water contained, from 11 to 38 per cent. afforded during distillation; and this is, of course, after it had been dried as usual in the open air. Indeed, far more than half the weight of turf collected, and allowed to drain in stacks for a short time, is really water; to drive off which would require much fuel, that would be an expense if peat was used for that purpose. Indeed, no feasible method exists for economical distillation of peat, except in using it as a source of heat to the retorts; for all peat localities are usually too far removed from coal districts to permit of the use of the latter as fuel.

A method of making illuminating gas that is exceedingly ingenious, but has not been adopted on the large scale, was that of combining the manufacture of water and coal-gas, and so of increasing the amount of gas thus jointly produced by water and coal, the hydrogen of the former uniting with a portion of the carbon of the coal, and thus increasing the quantity of hydrocarbons during the expenditure of the same quantity of coal, &c., which, according to the usual plan, would produce—say 9,500 cubic feet per ton. Water was first decomposed by passing its vapour over red-hot coke or charcoal, by which hydrogen and carbonic acid are afforded, as already mentioned. These gases were allowed to pass onwards into retorts, in which coke, coils of wire, &c., to diffuse the heat, were placed; and into these retorts fat or resin was allowed to flow. Exposed to a red heat, these latter substances afforded hydrocarbons, which were seized on, or united with the hydrogen and carbonic acid, previously mentioned. After heating these gases so charged with hydrocarbons, the carbonic acid was removed by the agency of lime, and the illuminating gas was collected in the usual way. This somewhat resembles the method of making water-gas as described and illustrated at pp. 602 and 603, *ante*.

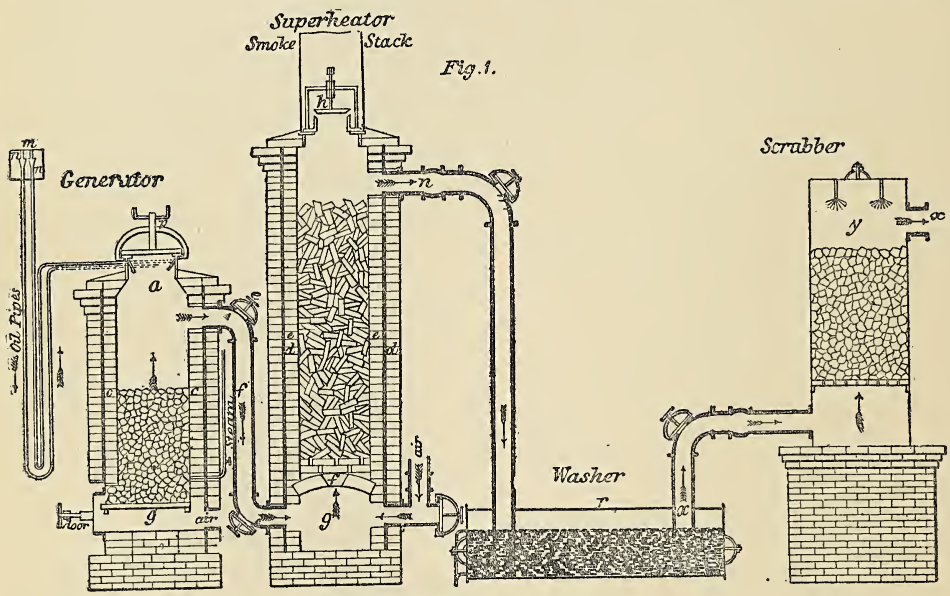


Fig. 424.—Water-gas Apparatus.

According to some authorities, gas equal in illuminating power to ordinary cannel, and having a specific gravity of 600 to 650, might be obtained at a cost of a little over 1s. per thousand cubic feet, taking into account only the cost of fuel and material. By a modification of the arrangement cannel coal could be employed in place of fat or resin in carbonising the hydrogen afforded by the decomposed water. By this plan double the usual quantity of gas was said to have been produced than by the ordinary method of simply distilling the coals in retorts, as described in the preceding pages.

Many engaged as professional chemists, or in the manufacture of the gas, reported highly in

favour of its merits. According to Dr. Frankland, Lesmahago cannel, which ordinarily only affords about 11,000 cubic feet per ton of about 25 or 26-candle gas, produced, by this method, 29,000 cubic feet, and having an illuminating power equal to 28·7 candles; whilst Boghead coal afforded 51,700, with a candle value of 17·9. Another authority placed the average results as equal to $2\frac{1}{2}$ times the value of a similar bulk of Newcastle coal-gas. Mr. Clegg stated, that a ton of Wigan coal yielding 10,000 cubic feet of 20-candle gas, afforded by this process 26,000 cubic feet of 12-candle gas. Similar results he obtained by using other coals. He found the average increase in quantity of gas thus produced by the united use of coal and water-gas, to be from 50 to 100 per cent.; and that, on an average, the gas could be produced at from 11*d.* to 15*d.* per 1,000 feet.

Either the gas companies have been blind to their own interests, and prefer to follow the "good old ways" of making gas from coal at a very moderate profit, to the neglect of this superb plan of doubling the product of gas from a ton of coals, or the entire results stated in the preceding account have been baseless as the fabric of a vision; for many years have elapsed since the method occupied the attention of many leading chemists and gentlemen professionally connected with the manufacture of gas, and yet it has never been adopted by any of the companies—as least so far as is publicly known. There is no doubt that the method is exceedingly ingenious and scientific; but, like many other of that class, it may have been too much so for all practical purposes.

At this point we may notice, that all kinds of inferior, and even rich, gases produced from coal, may have their illuminating power greatly increased by a very simple plan, and which has been partly described in the preceding account of the method of carbonising water-gas.

Hydrogen has a great power of dissolving, absorbing, or taking up certain substances; but especially hydrocarbons, and certain metals. Thus, if it be generated from water by means of iron or zinc filings and sulphuric acid in a suitable vessel, and a solution of arsenic be added, the hydrogen will attach itself to the metal, which will become volatile, and may be burnt with the hydrogen as a gas. Antimony may similarly be made to unite with hydrogen. If, again, hydrogen be passed through a vessel containing any volatile hydrocarbon, as coal-naphtha, benzole, &c., it will take up a portion; and although itself not luminous during combustion, will thus afford an excellent light. Indeed, common air, if moist, may be passed through benzole, and it will become luminous. It absorbs so much of the hydrocarbon permanently, that it may even be stored in gas-holders, and distributed thence through pipes, as is common gas, and yet retain this inflammability.

The process applied to ordinary coal-gas is called naphthalisation, and it is readily effected at comparatively trifling cost. Thus, if an air-tight metal box be loosely filled with broken bricks, coke, pumice-stone, or any other such

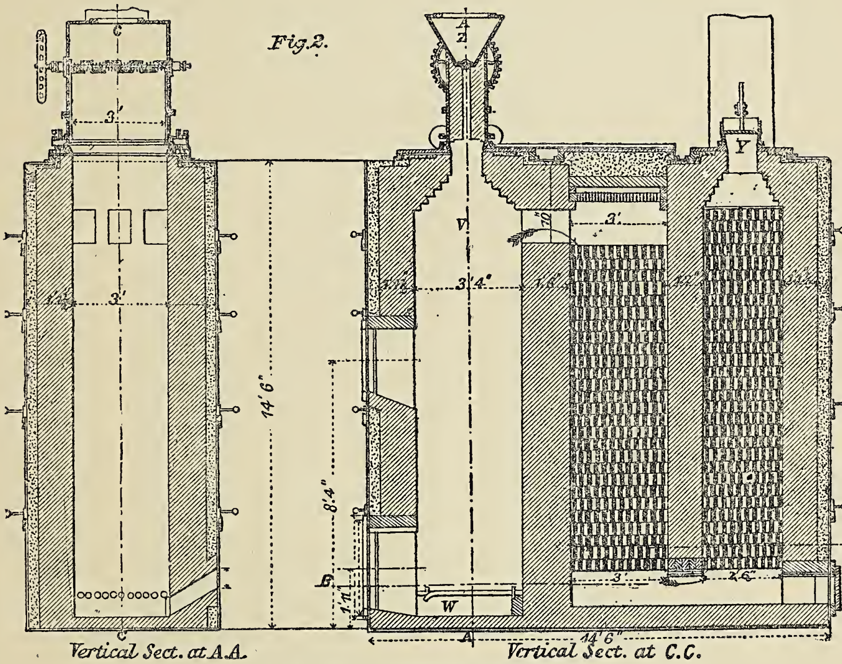


Fig. 425.—Water-gas Apparatus.

porous substances, that are to be sprinkled over with benzole and a little water, and inferior coal-gas be passed in at one end, and allowed to go out at the other, after it has traversed the materials thus wetted with benzole, its illuminating power is greatly increased, and a 12-candle gas may thus at once be rendered of greater illuminating power than even the best cannel.

We have been much surprised at the trifling degree to which this plan is adopted ; but, perhaps, this may arise through a general ignorance of the nature and value of the method. There is not the least danger nor trouble attendant on its adoption. The benzole is cheap enough at the present day ; and all that is required to keep up this improvement, is simply to add, occasionally, a little more benzole to that already sprinkled on the coke, to replace the loss by evaporation or union with the gas. The saving in amount of gas used for the same quantity of light is very great; the colour of the light is far purer and whiter, and, consequently, especially fitted for use in drapers' shops. Indeed, in some instances that we have seen of the adoption of this method, united with a careful mode of complete, but not over-combustion, the light has been too powerful for the eye to long withstand. A bat's-wing or fish-tail burner is, as far as we have experimented, the best form for burning highly naphthalised gas; as, indeed, both are for all gases rich in hydrocarbons.

But a few years ago it was attempted to convert the tar of coal into gas ; and several patents were taken out for that purpose. All failed, however ; and, had they not done so, they would have all been put aside, owing to the great value of the products of tar distillation, already described at p. 598, *ante*, and following pages ; where it will be found that the aniline, and other products, now obtained by distillation and certain chemical processes, are of infinitely greater value than any quantity of gas that could have been obtained by the most successful processes.

Gas as a Motive Power.—For some years past various attempts have been made to substitute gas for steam as a motive power, and considerable success has attended such attempts when only small engines are required. We quote the following remarks from *Engineering* as stating the present condition of the question :—

"At a congress in Brussels, in 1877, of the chief engineers of the French and Belgian associations for inspecting steam-boilers, it was the opinion of the meeting that steam-engines are not the motors for small industries. The reasons given for this opinion were that small boilers are difficult to examine, their repairs are very costly, and their life is comparatively short. It was agreed that the small motor of the future is to be found in electric, hot-air, compressed-air, hydraulic, or gas-engines. The last mentioned was justly regarded as that which has met with the greatest success.

"It is only natural that the stringent laws which regulate the application and working of steam-boilers on the Continent, should have the effect of increasing the demand for any practicable form of motor that does not come under harsh Government inspection with its severe tests and penalties, but we were scarcely prepared to find boiler engineers going, we might almost say, out of their way to advocate the use of gas-engines, as it is obviously against their interest, in some measure at least, to do so.

"Notwithstanding the favourable opinion of gas-engines entertained by steam-boiler engineers on the Continent, there still exists a very strong prejudice against gas-engines amongst engineers in general on this side of the Channel. This prejudice arose from the failure of the first gas-engines introduced from France some time ago. These engines were wrong in principle. It was overlooked by their inventors that the sudden but unsustained pressure consequent upon the explosion of a strong mixture of coal-gas and air exerted against a piston, was not so suitable as the sustained pressure of steam for obtaining a steady motion of a crank and flywheel. To this oversight, as well as to a considerable amount of complication, necessity for skilled attendance, trouble from heating, and expense of working, the failure of these first gas-engines was mainly due. There are still about a score of these engines working in this country, but most of those set to work have been abandoned or converted into steam-engines, a change which their construction readily admitted. The defect in principle has been entirely removed in the gas-engines of the present day.

"Nearly all the drawbacks attendant upon the use of steam, especially for small powers, are due to the risk, attention, and anxiety inseparably connected with the use of the boiler, and it must have occurred to many steam users what a blessing it would be if the steam-engine could be used without a boiler. Now, it is just this desideratum that a good gas-engine is designed to meet, and the success which has attended the introduction of at least one type of gas-engine renders it easy to predict with certainty that a large new field will be opened out for the employment of motive power, that many small industries will be greatly developed and extended, and new industries created, now that a cheap motive power can be employed without the risk and trouble of having a steam-boiler on the premises. For instance, the advantage of being able to start a gas-engine at full power by lighting a jet and turning the flywheel, instead of having to wait till steam is raised, renders it of great value as a fire-engine in country mansions and other isolated buildings, where it can also be used daily for pumping, lifting, laundry work, and ventilating. The gas-engine appears to offer to architects a way out of the difficulty they have hitherto found in efficiently ventilating buildings for want of a suitable motor. In crowded rooms fresh air can be drawn in from the most suitable side of the building according to the season, time of day, and locality, by means of a fan, and distributed and diffused where required without producing dangerous or unpleasant local draughts, which are only too often felt with the

present primitive, not to say barbarous, modes of ventilation still in vogue. The little attention given to proper ventilation in costly buildings, and the want of success hitherto in overcoming the mechanical difficulties in the way, are not very creditable to our architects and engineers.

"The destruction by fire of several buildings, recently has been ascribed to the presence of a steam-boiler on the premises. The danger from fire by storing or removing the hot ashes is greatly increased when the boiler is placed on any story above the ground floor. So great is this danger that the insurance rates are often so high as to preclude the use of steam-boilers by the tenants in the higher floors of a building and often leads to the exclusion of steam-power altogether on the part of the owner. This prohibition of the use of steam-power has proved to be a great tax on many small industries, and in the working of cranes and hoists in warehouses in London and other places where the cost of working hydraulic engines direct from the main is too great to admit of their use. The want of a suitable motor to work in the upper floors no longer exists, as gas-engines, working up to twelve-horse-power, can be applied without any more risk or trouble than accompanies the use of a steam-engine without a boiler.

"With respect to the comparative economy of working small steam-engines and gas-engines, this depends chiefly upon the relative prices of steam and of coal-gas. Taking the price of coals per ton, and that of gas per one thousand cubic feet in some towns in the north where cannel gas is used, the relative prices are two to one, whilst in London they are as five to one, so that if the cost of working were the same for gas and steam in Manchester, the cost of working in London would be over 50 per cent. in favour of the gas-engine, a slightly smaller quantity by volume of gas being required for a given amount of work when rich cannel gas is used.

"The Otto gas-engine is said to require not more than twenty-three feet of gas per indicated horse-power per hour. At London prices this is equivalent to about one penny per hour. A steam-engine, working at the same cost with coal at 18*s.* per ton, would take 13½ lb. per horse-power per hour. This appears at first sight a very extravagant rate of consumption even for a small steam-engine, say under eight-horse power. But as the superior economy of the gas-engine has been repeatedly proved where it has worked side by side with a steam-engine, it may be as well to inquire into the cause of the extravagant cost of working in many small steam-engines. These are used for many purposes where the resistance is very irregular, the power required varying, perhaps, from one to eight-horse-power. In a very great number of small steam-engines and boilers over, says four or five years old, the amount of steam lost by leakage at joints, taps, glands, slide-valves, and piston-rings, forms a large proportion of the quantity of steam generated, and the further great quantity of heat lost through the chimney, and by radiation from the furnace, boiler, and pipes, bears a not inconsiderable proportion of that utilised. As this waste is a pretty constant quantity, whether the engine is giving off one or eight-horse power, it follows that the amount of fuel used is not at all proportionate to the power developed. When the engine is indicating two-horse power, almost as much fuel may be used as when it is indicating six-horse. With a leaky safety-valve and steam stop-valve it sometimes requires a considerable quantity of coal to raise steam and keep it up a few hours at the working pressure even with the engine at rest.

"We grant this state of things is disgraceful, but we are speaking of things as we have too often found them, and not as they ought to be. There is little hope for improvement in this matter with many small steam users. As long as they have a boiler which furnishes them with a means of making up for the waste of steam and heat by wasting more coal, they prefer doing so to being at the expense of having their boiler fittings and engines put into good order. There are thousands of small boilers and engines at work, upon each of which the judicious outlay of a few shillings annually in necessary repairs would yield a return of as many pounds.

"In the case of a steam-engine and boiler in fair order, and doing intermittent work, there is always a considerable loss in getting up or maintaining steam. With the best forms of gas-engines the case is very different. When the engine is in fair order, the quantity of gas used is always in proportion to the power exerted. A certain volume of gas is drawn from the meter just when it is required. Should the engine not be in good order, and there is an escape of the expanding gases past the piston-rings, there will be a waste and loss of power, and more gas will be required, but this loss soon reaches its limit. An engine, say, of the Otto type, cannot use more gas than the quantity corresponding to its maximum power. Such an engine, working up to within 25 per cent. of its greatest power, cannot waste more than 25 per cent. of the greatest amount of gas it is designed to use. When the piston-rings require renewal, the defect is made manifest by the escape of the burnt gases, and in order to regain the power which the engine loses in consequence, the rings must be renewed, and so economy is mercifully forced upon the user. In a steam-engine, on the other hand, the waste of steam in escaping past the piston is easily made up by burning more coal, and this waste is only limited by the quantity of air that can be made to pass through the fire-bars. The above consideration will serve to show why it is that in practice gas-engines are often found to work at one-third the cost of small steam-engines they have replaced.

"Besides the economy of fuel there is also a great saving in attendance where a gas-engine is used, as there is no stoking and maintenance of pressure and water-level requiring special attention. When oiled and started the engine can be locked up and left to itself for hours like a steam-engine. The handiness of the gas-engine was strikingly illustrated in the Royal

Albert Hall, at the recent exhibition of electrical light apparatus. In the course of the lecture, the engine in the body of the hall upon a given signal was started from a state of rest, the belt slipped on to the pulley and the light produced all in a few seconds. The engine might be left for a week or more, and the same thing repeated without any preparation.

"Gas-engines may be often used with great advantage as auxiliaries to large steam-engines. In many works a steam-engine of over 50-horse power is run all night to drive a long line of shafting in order to work a small machine requiring not more than a couple of horse power. The loss in coal, attendance, and wear and tear is often very great when this work is often repeated. By using small steam-engines the evil is only partially remedied, as the fireman has to be in attendance. To meet such cases, gas-engines have been applied with great advantage, as the man who attends to the machine can start the engine and give it the little attention it requires, and the cost of working is reduced to a minimum.

"It is, however, in connection with small industries that gas-engines will be most largely employed in the future. Where steam is required for heating, boiling, and other purposes, the steam-boiler will always hold its ground, but for many minor industries we may say that the days of small steam-boilers are numbered."

Heating, Warming and Cooking by Gas.— These applications of gas are yearly getting more extensive. At first for all these purposes great prejudice existed on the part of the public mind at least so far as this kingdom was concerned. In Paris, and other places on the continent, gas is largely used thus, and in fact a considerable revenue of the Paris Gas Light Company is derived from such sources. Very recently the London Gas Companies, in asking further powers in new Acts of Parliament, have included these objects, and have even asked for permission to manufacture stoves and other necessary apparatus for the purpose of cooking.

Of course in the case of warming by gas provision should be made for the escape of the products of combustion, otherwise, in close apartments, serious and perhaps fatal results may ensue. This is a subject, however, to which we shall have to draw special attention at a subsequent page, when dealing with the methods ordinarily in use for burning gas for illuminating purposes.

Despite the great advances that have been made in the application of the electric light in recent years, for lighting streets, public buildings, &c., and which will be fully dealt with hereafter, we are of opinion that the interests of the Gas Companies will suffer but little from that source. The uses of gas are constantly increasing, and if the companies keep pace with the growing demand of their customers in regard to the quality and price of the article they produce, they will not have much to fear from competition by other illuminating agents.

We have thus described the chief of the possible, probable, and practically impossible sources of gas for illuminating purposes; having endeavoured to give, as near as practicable, an impartial account of each, not only to interest the general reader, but also as a guide to the practical man. It is difficult, however, at all times to be really impartial; because each person who has an opinion on any subject, will, generally, give the greatest weight to those of others that most side with his own. We can, however, honestly plead an utter impartiality, so far as we are personally concerned, on the ground of having not the most remote interest in any question that has been discussed, except so far as it proceeds from a desire to place all matters that have been dealt with in a light strictly in accordance with the present condition of chemical science. In frequent instances we have compared the opinions expressed to us by gas managers of entirely opposite views; and have endeavoured to mould each in repeating them here, so that truth, rather than prejudice, should be followed. It is a remarkable peculiarity of human mental nature, that two individuals, or any number divided into two sets, shall come to almost precisely opposite conclusions, drawn from the same facts or premises. A singular instance of this, highly pertinent to our subject, and, indeed, of great importance in gas and paraffin-making, occurred some years ago in reference to the Boghead coal. On each of the repeated trials that have occurred in reference to the lessorship of the first-discovered mine, and also in regard to the patent rights of Mr. Young in manufacturing paraffin from it, the highest scientific authorities of the day have been pitted before juries against each other; one side swearing that it is a coal, and the other that it is only a shale—hence called the Torbane Hill mineral. At one time the dispute became, indeed, a *cause célèbre* in scientific jurisprudence; but of late years the conviction has gradually been arrived at, that the substance is really a coal, containing a larger amount of hydrocarbons and ash than any known kind.

In connection with many subjects that have to be dealt with in this work, precisely the same difficulty occurs. Thus, the constitution of olefiant gas and paraffin has been very differently viewed by men of science. But we need not multiply such instances, and only cite them as a weapon of defence against any who feel disposed to criticise some of the opinions or facts that we have advanced, which, having been done only with a scientific spirit, may be safely left to the judgment, favourable or otherwise, of all actuated by similar motives.

Before entering into the consideration of the best modes of burning gas, ventilation of rooms in which it is employed, and allied subjects, we shall give some short description of the methods that have been proposed for the examination of the commercial value of coal-gas, as now adopted by those who are officially appointed to report on the same, according to the provisions of the act of parliament; and by which it was hoped such a control could be exercised as would insure the consumer a full candle-value gas for

his money. In this, as in matters just referred to, great difference of opinion exists as to the most certain method of analysis or examination; and it has occurred that the reports of one officer adopting one method have not only been disputed before the magistrates whose business it was to adjudicate, but that such reports have been entirely set aside by evidence opposed, in principle and detail, to that adopted by the official inspector. We shall see that considerable difficulty occurs, in all cases, to obtain anything like accurate results in respect to the candle value of gas by the photometer, or any other method: hence the uncertainty and inconclusive results frequently obtained, although quite unintentionally, have been, and, perhaps, long will be, grounds of bitterness between the companies and their customers.

Up to a recent period, the London Gas Companies exercised their full, not so arbitrary powers over their customers. So far as private houses are concerned in the metropolis, it is only a matter of choice on the part of the tenants as to what illuminating agent they may employ. The paraffin lamp has become almost an institution among us, from the highest to the lowest, and the gas-candle has been a most welcome addition to the household as a substitute for the abominable dip-candle—we have not seen a tallow mould candle for years, they having been entirely replaced by the paraffin, stearine, and similar candles, and even the lower classes have found them more economical than the old tallow candle.

But to the London shopkeeper gas is absolutely essential. For the greater part of the year he has to depend on it for the sale of his goods, and a deficient or impure supply is equivalent to a heavy loss in his daily takings.

About 1870 the public feeling was strongly excited against the Metropolitan Gas Companies. In the outlying districts the shops and streets were often so badly lighted, as simply to make darkness visible. The price charged was exorbitant, for as the companies were allowed by their Acts to charge such a price as would enable them to pay the shareholders 10 per cent. per annum, the last penny was squeezed out of the customers to satisfy this condition. The meters also were generally against the consumers, who were charged for gas they had never used. In one instance that came under our notice, the quarter's gas account was charged at the rate of seven times as much as the gas company's meter had shown to have been consumed.

At last a government commission was issued to inquire fully into the matter. The complaints of the consumers were generally well established. It was proved that the companies made their gas without "due care and management;" in fact, in a reckless and wasteful manner, the cost of which, as already stated, fell upon the helpless consumer. Stringent conditions were subsequently imposed on the companies, and whilst their right to earn dividends was still secured, precautions were taken to prevent what was really no better than previous frauds on the public. The "manufacture" of fresh capital was controlled, as this had been an engine by which any surplus of dividend on the old capital was spread in the new. So effectually had this been done, that many of the companies' shares were sold at £250 each, where only £100 had been primarily paid. The newly created shares had to be sold by auction, giving to the public not only a control on the price, but also the opportunity of becoming shareholders. If the net revenue was more than sufficient to pay a dividend of 10 per cent. on the ordinary shares, then the price of gas was to be reduced in ratio to the increased dividend.

Of course the companies thought they would be ruined, as most manufacturers have thought when government has interfered with their monopoly. Instead of this, however, the shares and dividends both rose, while the price of gas lowered, but the consumption largely increased.

A powerful stimulus to the gas companies was found in attempts to make the electric light a general illuminating agent. In 1878, at Paris, it was successfully employed for that purpose. Many previous difficulties were overcome, and by 1881 it was adopted for the main thoroughfares of the City of London, and by the Metropolitan Board to illuminate the Thames Embankment, some of the bridges, &c. This is a subject which will have full attention paid to it in another part of this work.

Differences of opinion have occurred in respect to the impurities present in coal-gas, which we have disposed of at p. 574, *ante*, so far as the detection goes. One party considered the bisulphide of carbon, so frequently present, as not being in the least detrimental, during combustion, to furniture, books, &c., by the production of sulphurous, and, consequently, of sulphuric acid, as described at p. 574, *ante*. On the other hand, certain inspectors held a directly opposite opinion, averring that the existence of this compound is a most serious affair as an impurity of the ordinary London gas; "for it has been shown by Dr. Letheby, in several of his reports to the corporation of London, that bisulphide of carbon, in the act of burning and oxidising, forms sulphuric acid, a great portion of which escapes in a corrosive form, and does enormous damage to every kind of textile fabric. He states that the books in almost every library in the kingdom, where gas is used, are falling to pieces from the action of this acid on the covers; and he makes reference to the libraries of the Athenæum Club House, the London Institution, the Royal College of Surgeons, the Portico Library at Manchester, and that of the Literary Society at Newcastle-on-Tyne, for examples of the mischief done." We have already spoken of this at p. 574, *ante*.

Opposed to this is a report of Mr. Versmann (formerly assistant in the laboratory of the late Dr. Graham, one of our most eminent chemists), made in 1861, to the engineer of the Commercial Gas-works, respecting the amount and effects of bisulphide of carbon in the gas generally supplied by the London gas companies, and who adopt that report to the present day, as a defence against the attacks of all those who

believe in the harmful effects of the bisulphide of carbon.

Mr. Versmann's method of search for sulphur as bisulphide of carbon was as follows:—"The usual way of determining the sulphur of the bisulphide of carbon, is to burn the gas, thereby producing sulphurous acid, which is collected, converted into sulphuric acid, and then estimated as sulphate of barytes. The only difficulty in this process is the complete absorption of the sulphurous acid, which was secured by the following arrangements:—

"A small air and gas-burner was placed inside a very spacious retort, open at the bottom, and afterwards closed by dilute ammonia, contained in a suitable glass vessel. The retort was then connected with two Woulfe's bottles, the first of which contained a solution of ammonia, and the second a solution of iodine in iodide of potassium; the gaseous products of combustion were forced through these liquids by means of strong air-currents produced by a water aspirator, and were thus absorbed.

"The solution of iodine was used merely in case some of the sulphurous acid should escape unabsorbed; but it was found, in all these experiments, that not a trace of it could be detected in the second bottle.

"The sulphurous acid combined with the ammonia to form sulphite of ammonia, which was then converted [or, rather, so far as the sulphur was concerned] into sulphuric acid, precipitated by chloride of barium, and weighed as sulphate of barytes. * * * In order to be sure of a constant pressure of the gas, and thus of allowing the operation to go on safely for a length of time, a small delicate regulator was placed between the experimental meter and the burner, by which arrangement a certain maximum of pressure could not be exceeded; this was the more requisite because the variation in the pressure at the works was necessarily very considerable; and, without this regulator, the combustion might take place too quickly, the resulting carbonic acid not being drawn off in the same ratio, which might ultimately extinguish the flame."

Mr. Versmann obtained considerable variation as the results of his experiments; the amount of sulphur obtained in the combustion of 100 cubic feet of gas, varying from about 3 to 9·4 grains, the difference occurring in the use of the gas supplied by various companies. He explains this as follows:—

"The variation in these results appears, at first sight, considerable; and it may be difficult to find a precise explanation; but the subsequent calculations would show that even the largest quantity is comparatively so small, that the difference becomes very insignificant.

"The formation of bisulphide of carbon greatly depends upon—1st. The dampness of the coals; because, in very damp coals, all sulphur will, most probably, be converted into sulphuretted hydrogen. 2ndly. The degree of heat to which the coals are exposed [in the retorts we presume]: and, 3rdly, upon the quantity of sulphur present in the coals.

"It is evident, therefore, that experiments made at various times, and made with gas produced at different works, must lead to somewhat different results; and I think that the uniformity in these experiments is far greater than could have been anticipated.

"In proceeding to the practical view of the question—*i.e.*, whether this amount of sulphur may possibly become in any way injurious or obnoxious to persons inhaling the atmosphere of places where the gas is burnt—we must enter the dry field of calculation; for numbers [figures] always speak for themselves.

"One hundred feet of gas are found to contain 2·99 grains; 6·35 grains; 9·41 grains of sulphur, as bisulphide of carbon [respectively in three experiments].

"The specific gravity of yours [the Commercial Gas Company] is equal to 0·440; and I will assume the gas of the Chartered Gas Company to be of the same specific gravity. One hundred cubic feet of air weigh 56,490 grains, and, consequently, 100 cubic feet of gas weigh 56,490 × 0·440 grains = 24,856 grains; which contain 2·99 grains, 6·35 grains, and 9·41 grains of sulphur respectively, corresponding to 0·012, 0·026, and 0·038 per cent. by weight of sulphur; or 10,000 parts, by weight, of gas contain 1·2, 2·6, and 3·8 parts by weight of sulphur respectively. Or, if we compare the relative proportions by volume, we arrive at even smaller numbers [figures], in consequence of the specific gravity of bisulphide of carbon vapour being high—namely, 2·66 [air = 1·00]. I speak here of the vapour of bisulphide of carbon, and not of that of sulphur; because it will be more correct to compare the volume of the gas with the volume of the first [named] vapour. The sulphur vapours have a specific gravity of 6·65; the calculation shows that one volume of bisulphide of carbon consists of half a volume of carbon vapour, and one-third of a volume of sulphur vapour.

"The preceding quantities of sulphur—viz., 2·99 grains, 6·35 grains, and 9·41 grains [therefore], correspond to 3·55 grains, 7·22 grains, and 11·22 grains of bisulphide of carbon.

"As 100 cubic feet of air weigh 56,940 grains, 100 cubic feet of the vapour of bisulphide of carbon must weigh 56,940 × 2·66 = 150,263 grains; and, again, if 150,263 grains have a volume of 100 cubic feet, 3·55 grains, 7·22 grains, and 11·22 grains have a volume of 0·00236, 0·00480, and 0·00747 cubic feet. These fractions of cubic feet of bisulphide of carbon vapour are contained in 100 cubic feet of gas; or, in other words, 10,000 cubic feet of gas contain 0·236, 0·480, and 0·747 cubic feet respectively of the vapour of bisulphide of carbon.

"The result of these experiments, then, is, that the gas contains, in 10,000 parts by weight, 1·2, 2·6, and 3·8 parts of sulphur; and 10,000 parts, by volume, contain 0·236, 0·480, and 0·747 parts of bisulphide of carbon; and it may, without hesitation, be affirmed, that such a small quantity cannot have the slightest injurious effect, and that, even if the quantity was much larger, it would nevertheless be innocuous.

"To give a still more convincing demonstration of the infinite smallness of these numbers, I will now compare the products of the combustion of gas; and here, again, I shall be supported by the indisputable authority of calculation.

"The principal product of the combustion of gas, besides water, is carbonic acid—a gas which does not sustain animal life; being, on the contrary, injurious if inhaled in an excessive quantity.*

"It will, therefore, be interesting to find the relative proportions of carbonic and sulphurous acids, formed by combustion of a certain quantity of gas.

"In calculating the quantity of carbonic acid produced in burning gas, we find that 100 volumes form about 50 volumes of carbonic acid. The olefiant gas yields twice its volume, and light carburetted hydrogen its own volume of carbonic acid. Assuming the gas to contain, in 100 volumes, on the average, 5 volumes of the former, and 20 volumes of the latter, this would give 50 volumes of carbonic acid, which is certainly below the actual result.

"The bisulphide of carbon, on being burnt, produces sulphurous acid—a gas which is destructive if present in any sensible quantity, and which it would certainly be very desirable to banish altogether by some practical means.

"In forming sulphurous acid, the sulphur combines with two equivalents, or exactly its own weight of oxygen, yielding twice its weight of acid; so that the 2·99 grains, 6·35 grains, and 9·41 grains of sulphur, will produce 5·98 grains, 12·70 grains, and 18·82 grains of sulphurous acid.

"In order to compare these quantities with the volume of carbonic acid, it will be necessary to remark that the specific gravity of sulphurous acid is [gaseous] 2·247; and thus, to make a calculation as before:

"As 100 cubic feet of air weigh 56,490 grains, 100 cubic feet of sulphurous acid weigh 56,490 grains $\times$ 2·247, or = 126,933 grains; and, again, if 126,933 grains have a volume of 100 cubic feet, 5·98 grains, 12·70 grains, and 18·82 grains have a volume of 0·0047, 0·0100, and 0·0148 cubic feet.

"These numbers represent, together with about fifty cubic feet of carbonic acid, the products of combustion of 100 cubic feet of gas; or, comparing these proportions in larger numbers, we find, that in burning gas, with every 50,000 cubic feet of carbonic acid, 4·7, 10·12, and 14·8 cubic feet of sulphurous acid are formed and distributed into the atmosphere.

"The sulphurous acid has certainly far more destructive properties than carbonic acid, although the last does not support combustion nor animal life; but it is quite out of the question that these small quantities of sulphurous acid could have any injurious effect upon the human constitution, while the enormous quantities of carbonic gas formed at the same time should have no effect whatever.†

"I am of opinion, that before any person could be inconvenienced by these quantities of sulphurous acid, he must have ceased to live, long previously, from the effect of the carbonic acid.

"The fact is, in examining this question, it has generally been neglected to make proper allowance for this circumstance, that all our houses and rooms are so well and constantly ventilated [?], that any dangerous accumulation of gases cannot easily take place.

"It would, indeed, be highly desirable to remove even these traces of bisulphide of carbon from the gas, because we naturally wish to have as few impurities as possible in the atmosphere; and we are quite justified in doing our utmost to get rid of them; but I very much question whether the removal of bisulphide of carbon from the gas would be the first and most important point, if we were seriously bent upon ameliorating the atmosphere of our houses, especially in large towns.

"I think far too much importance has been given to this subject, most likely from no extensive experiments having been made, or proper comparisons drawn, with other causes tending to impair the state of our atmosphere.

"Before concluding these remarks I will subjoin a parallel example, which, I trust, will be as convincing as the former statement. It is well known that our common lucifers are prepared by dipping pieces of wood into melted sulphur, and afterwards into a chemical composition, which, upon friction, produces ignition. It is somewhat surprising that this branch of industry is almost in a state of infancy in England, when we consider its progress elsewhere; and I have often found that the lucifers in common use here contain two or three times as much sulphur as is required, and even more.

"No one imagines that any serious injury or deterioration of the state of the atmosphere can take place from lighting a lucifer in a room; and yet, when we come to compare the amount of sulphurous acid thus produced with that resulting from burning a certain quantity of gas, we shall soon find that the danger is in one case as great as in the other.

"I determined, with this view, the quantity of sulphur adhering to a variety of lucifers, taking twelve matches, converting the sulphur into sulphuric acid, and determining this as sulphate of barytes. I hereby arrived at the result, that a great variety of lucifers have more than one grain of sulphur a-piece.

"We may assume that a large lofty room is lighted with four gas-burners, each consuming five cubic feet of gas per hour, and that their flames burn for five hours in order to consume 100 cubic feet of gas, containing 2·99 grains, 6·35 grains, and 9·41 grains of sulphur.

"The same quantity of sulphur would be burnt by lighting, during the five hours, three, seven, or ten lucifers; and I really do not think that any one could entertain the slightest fear

* This is a very mild account of one of the most dangerous gases known; the presence of 5 per cent. of which in air renders it not only "injurious" to life, but really poisonous.

† This is incorrect, if intended to apply to the combustion of gas in an apartment; but we presume that the author is speaking of a ventilated place.

in so doing, although the phosphoric acid simultaneously produced may be, perhaps, even more in quantity than the sulphurous acid. I am sure that this one instance will suffice to illustrate how unfounded is the apprehension of injury from the effect of the sulphurous acid; and I must say that the quantity of sulphur found in these experiments must become much larger before any reasonable fear could be entertained."

We have thought it due to the impartiality we profess, to give, *in extenso*, the preceding report, because it states the defence side of the gas companies, who are necessarily in opposition and at issue with the official inspectors of gas at all times, but especially on the question of the presence of sulphur in the gas. It will be evident that Mr. Versmann's views are directly opposed to those of Faraday, Letheby, and many of our most able chemists. It will also be noticed that he has not said one word about the amount of sulphur produced by the combustion of the sulphuretted hydrogen, almost constantly present in London gas, and a much more abundant source of sulphur, and sulphurous and sulphuric acids, as already mentioned at p. 574, *ante;* and for the removal of which, lime, oxide of iron, &c., are so largely used by the gas companies.

We must, however, now leave the subject, and the disputes it occasions, to the opinion of our readers; those of whom, practically or professionally engaged in gas-making, &c., will be best capable of judging on which side of the question the greatest amount of truth lies.

Analysis, Etc., of Gas.

From the peculiar nature of coal-gas, and its exceedingly complex composition, its analysis presents many difficulties; so many, in fact, as to make the operation barely possible in regard to even approximate accuracy.

Consequently, numerous methods have been proposed, at least for estimating the commercial value of gas; and it will now be our business to investigate some of these; for to embrace all that have been proposed, would trench too largely on our space.

Generally we may class all the plans that have been followed under the heads of physical and chemical. The first embraces questions of specific gravity and photometry; and the latter, all the various modes of chemical analysis that have been tried, with a greater or less amount of success.

We shall first notice the specific gravity, which is one of a physical character, and proceeds on the assumption, that the richer the gas the greater is the proportion of hydrocarbons it contains. As a general rule, this is true; but, on account of nearly every other gas being heavier than coal-gas, and all so than hydrogen; because, also, there may be present carbonic acid and oxide, air, &c., in coal-gas, this test may at times prove fallacious. The test of specific gravity, therefore, should generally be united with the use of some chemical mode of testing, so that the one may check the other. Although the term "specific gravity" has been frequently used in the preceding pages (and we have presumed that our readers have fully understood it), still it may be desirable that a slight explanation be here given of its meaning.

The specific gravity of a body denotes its relative weight, bulk for bulk, when compared with other bodies. Thus, if an equal bulk of water, lead, and platinum were taken, and supposing that the water weighed just one ounce, then the similar bulk of lead would weigh $11\frac{3}{4}$ ounces, and that of platinum twenty-one ounces. Of course, some standard of specific gravity must be chosen; and, for liquids and solids, water, at about 62° Fah., is that standard.

If a bottle held exactly 1,000 grains of water, but was filled with the strongest sulphuric acid, the weight of the latter would be, bulk for bulk with the water, 1,840 grains; whilst if alcohol or spirits of wine were used to fill the bottle, the latter liquid would weigh only about 830 grains.

Now, in each of these cases, the ratio of bulk and weight between the water and the solids or liquids, is called the specific gravity: that is, in each instance we have adduced, the substance or fluids named will have a specific gravity, of water, 1·00 as the standard; lead, 11·45; platinum, 21·00; sulphuric acid, 1·84; and spirits of wine, being less than water, that of 0·830. It will be unnecessary for us here to enter into any questions as to the method of taking the specific gravities of either solids or liquids, because such an inquiry is not pertinent to our present objects.

In regard to gases, it is evident that water would be far too gross a standard. Atmospheric air, bulk for bulk, weighs only about the $\frac{1}{820}$th or $\frac{1}{840}$th of the weight of water; that is, a pint of water weighs about 830 times as much as one of air would do. But pure hydrogen gas weighs still less, relatively, being less than one-fourteenth of the weight of the same bulk of air. Some gases and vapours, on the other hand, weigh more than air; as, for example, carbonic acid, hydrochloric acid, sulphurous acid gases, with several others.

Referring generally to our previous pages, coal-gas varies upwards from 0·400 to 0·750, the former representing a low average of London gas, and the latter a good Boghead cannel; whilst oil-gas is much richer than any in hydrocarbons, and reaches a specific gravity of 0·900. It is evident, therefore, that, with the limitations already pointed out, the specific gravity test may be considered as an extremely valuable indicator of the quality of our gas supply. Before entering into an account of the method that must be adopted in taking the specific gravity of coal-gas specially, some general remarks on gas manipulation may be useful to our practical readers unacquainted with such methods; and we have met with more than one gas manager who required such information.

Gases may be divided practically, for our

purpose, into two classes—those condensible, and such as are non-condensible, in water. Here we may remark, that for all experiments with gases in which water is required to be used, only that should be employed which has *recently* been boiled and allowed to get cold; because all rivers, springs, and other waters exposed freely to the atmosphere, contain oxygen, nitrogen, carbonic acid, and other gases in solution.

If, for example, coal-gas be collected in the manner we shall presently describe for examination, by allowing it to bubble through water, all the condensible gases it may contain, as carbonic acid, and sulphuretted hydrogen, would be taken away from it, owing to their solubility in water. Indeed, the gas would undergo a second purification, and thus have abstracted from it two gases at least, the object of which, in gas analysis, is to detect rather than lose.

Two methods are usually employed, therefore, to collect gases for examination. One is by means of a water-trough, in which any vessel, open at one end, is plunged, but filled with water; and its open end is then introduced into water, that should nearly fill the trough. The plan is called the pneumatic trough method, and arrangements are specially made for the purpose by the instrument-makers. Such are, however, entirely unnecessary for all practical purposes, a basin or pail, nearly filled with water, answering every purpose. Then, supposing we desired to collect a quantity of gas from coals, for examination, we should proceed as follows:—Two or three glass-stoppered or well-corked bottles, the necks of which should be smeared with tallow, to keep either the stopper or cork tight, may be provided. The bottle is dipped into a pail of water till filled, and the *open* end is then inverted, and allowed to rest at the bottom of the pail. A small-bore india-rubber pipe is fitted to the gas-burner, and the tap turned on so that all the air the pipe may contain is expelled.

With the left hand one of the bottles is then to be raised in the pail, so that its open end shall remain an *inch below* the surface of the water. This will, of course, prevent the water in the bottle from running out. The end of the india-rubber pipe is then to be passed under the open end of the bottle, when the gas will bubble up, soon filling the jar, the stopper or cork of which is then to be inserted into the neck, *still below the water.* The bottle may then be removed, and the gas be kept for weeks if necessary, without any danger of deterioration, provided the cork or stopper fits accurately gas-tight.

Of course it may readily be transferred into a larger or smaller vessel when needed, by pursuing precisely the same plan as that just explained. For example, in the margin is represented a most essential vessel in gas analysis. It is a glass jar, furnished with a stopcock, and open at its lower end. On one side it is graduated into cubic inches, by which means any quantity less than its total capacity can be readily measured off. To fill this it is only requisite to open the stopcock, and press the glass jar into a vessel of water deeper than itself. The air will escape by the stopcock; and when all is removed, the cock is closed. A bottle, filled with gas, as just directed, is then placed, mouth downwards, in the water of the pail. On its stopper being removed, beneath the water, and under the open end of the graduated glass jar, all the gas it contains will pass out, and be transferred to the graduated vessel; and from these the gas may afterwards be transferred to any other vessel by means of a connector at the top of the stopcock—a mode of proceeding that will at once suggest itself to all acquainted with gas matters. Bladders, gas-holders, glass flasks, &c., may be thus filled with any chosen number of cubic inches.

Fig. 426.

The second method is precisely similar in principle, but varies in detail. As we shall have to allude to it hereafter more particularly, it will be sufficient, for the present, to state that a small trough is used, and small glass vessels; because, in place of water, the fluid metal, mercury, is employed. The reason of this is, that mercury absorbs none of the gases contained in coal-gas; and, consequently, the carbonic acid, sulphuretted hydrogen, &c., will not be lost, and a serious cause of error, that would arise by the water method, is avoided.

For many purposes a small gas-holder is of considerable use, because, instead of the trouble of filling a number of bottles, a large quantity of gas can be stored in one vessel for removal to any other place than whence it was obtained. A small instrument, constructed on the principle of the ordinary holder of the gas-works, will answer extremely well. In the laboratory, however, the following forms of the instrument are more usually adopted. In Fig. 427 an ordinary sulphuric acid carboy, without the external wicker covering, is represented as the holder: *b* is a

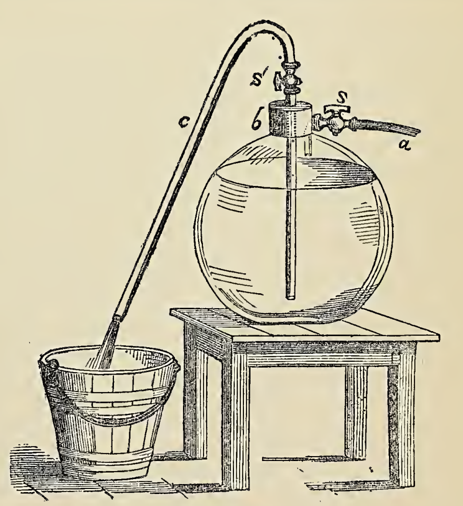


Fig. 427.

brass cap, fitted air-tight on the neck. On the right-hand side is represented a stopcock, S, attached to a pipe, *a*, by which the gas is sent into the holder. *c* is a syphon, that fits by a ferrule to the stopcock, S′. The mode of using this instrument is as follows :—In the first place, the vessel is filled with water, which is done by fitting in a funnel at S′, and opening the stopcock, S. The fluid will enter at *b*, and drive out all the air. When the vessel is full both cocks should be closed. A syphon, *c*, is then to be screwed on to the stopcock, S′, or affixed to it by a union-joint ; and the pipe, *a*, which should be an india-rubber tube, is connected with the source of the gas to be collected. Both stopcocks may then be opened, S′ and S ; and in collecting coal-gas, because the pressure is very slight, it is desirable to suck the lower end of *c* with the mouth, and so to draw the water over through the syphon-pipe. As soon as this is effected the ingress of the gas will be sufficient to drive out all the water, whose place it will take. Both stopcocks should then be at once closed.

To use the gas—that is, to remove it from this form of holder—a slight alteration of the preceding arrangement must be made. In Fig. 428 *f* represents a funnel that is screwed into the

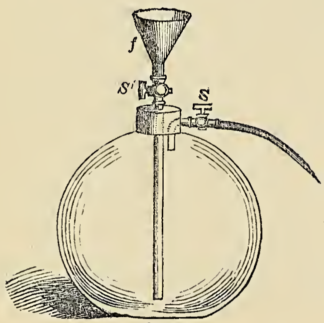


Fig. 428.

stopcock, S′. To remove the gas, the stopcock, S, is opened simultaneously with that marked S′; and if water be poured into the funnel, *f*, it will run down the pipe represented in both engravings, and which is fixed air-tight in the collar at the neck, to the bottom of the vessel, and as much gas will be forced out at S as there is water, bulk for bulk, poured in.

Both engravings represent the conversion of a sulphuric acid carboy into a gas-holder ; a convenient form of the arrangement is that of adapting the same plan to an ordinary two or four-gallon stone spirit-bottle, enclosed in wicker-work. The best cement that we have yet used for fixing on the cap, *b*, to the neck, either glass or stone, is shell lac dissolved in methylated spirits or spirits of wine, to the consistence of treacle ; and, next to this, gutta-percha cement.

Cheapness, however, is the chief recommendation of the gas-holder just described. In the laboratory, and for general use, the following form is by far the most eligible :—

This form of gas-holder consists of the following parts :—It may be made of tin, zinc, or copper sheet. A is the vessel holding the gas ; B a cistern or tray, holding water ; C a stopcock, leading to D, a pipe that reaches to the bottom of A. On one side is a gauge, E E, graduated

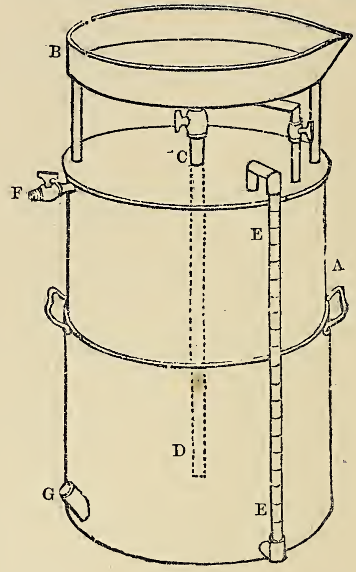


Fig. 429.

into cubic inches, by which the quantity of gas measured off or stored in the gas-holder may be judged of. F is a stopcock, by which the gas may be withdrawn; and G an opening, covered with an air-tight cap.

The gas-holder is used as follows :—The stopcocks, C and F, are first both opened. Water is continually poured into B, and, passing down the pipe by the stopcock, it will drive out all the air, which will escape at F. On this occurring both stopcocks are closed. The cap at G is then unscrewed ; before doing which, however, the gas-holder should be put over a tub or sink, to catch the water that will afterwards be forced out. Only a little water will escape at G until the pipe from which gas, or the stem of a retort producing gas, be inserted into the opening, G. The gas will then rise in the holder, forcing the water out at G ; and before the water-level is reduced to G, the pipe supplying the gas should be removed, lest air enter. The gauge will indicate when this should be done. The cap is then to be screwed air-tight on to G.

To remove the gas an india-rubber pipe is first fitted on to the stopcock, F, so that the gas may be conveyed to any desired place. Water is then poured into the tray, B, to fill it. The stopcock, C, is next to be opened, when the water from B will run into the holder, A. If the stopcock, F, be now opened, the holder may be gradually emptied of gas.

If these holders be used, but especially if for the lime-light (to be hereafter described), it is desirable that a holder should invariably be used to store one gas only; that is, one should be kept strictly for hydrogen, and another for oxygen, otherwise serious accidents may occur

from explosion, as resulting from a possible accidental mixture of the gases. We narrowly escaped death from such an accident some years ago.

Formerly bladders were largely used for experimenting with gases; and, from that fact, there is little doubt that great injury has been caused to the credit of early experimenters. All membranes are porous; and, as such, permit of the egress of the enclosed gas, and the ingress of air; and thus, whilst the bladder may, for some time after, be fully distended, as might be supposed, by the gas with which it has been first filled, the fact really may be, that a large proportion of air has entered. It is on this principle that the very valuable method of dialysis, invented by Dr. Graham (already referred to in connection with the diffusion of gases), is founded.

India-rubber bags have also been much used; but the same objection occurs to them as is offered against bladders. We have had several, and have incurred great expense; but never found one really gas-tight at first; and, in every case, they split at the seam, after much use. They may then be patched up by india-rubber cloth and cement, but can never be implicitly trusted. If employed in experiments with oxygen and hydrogen, it is still more important than with gas-holders, that the bag for each gas should be kept distinct in use; for it is exceedingly difficult to completely empty an india-rubber bag before fresh filling it with gas.

Having thus described some of the instruments desirable for use, even in experiments with coal-gas, we now turn to the question of ascertaining its specific gravity, as one test of its quality.

The usual method is to employ a glass globe, to which a stopcock is fixed. This is represented in the annexed cut, *a* showing the stopcock, and *b* the globular part of the glass vessel, which should be as light as is consistent with strength. Great care must be taken that the junction of the cap of the stopcock and neck of the glass vessel is perfect, lest air might enter; and equally so that the tap of the stopcock fits accurately and air-tight in its socket. To ensure this, even with the best workmanship, the tap should be withdrawn, and smeared over with a little beeswax that has been melted with olive oil. Nothing is more important than care in this respect; for the admission of air with the coal-gas would apparently give the latter a far higher illuminating value, owing to the false rise of specific gravity that would be thereby occasioned. A still better arrangement is that in which a stopcock is affixed to the two opposite ends of a glass vessel, as then it can be far more certainly filled with gas, to the exclusion of the air.

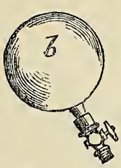


Fig. 430.

Supposing, however, that the globe, with either one or two stopcocks, is used, the method of procedure is as follows:—The globe is attached, by means of a ferrule, to an exhausting syringe, and the cock, *a*, being opened, all the air is exhausted to the utmost possible degree. The stopcock is then to be closed, and the globe should be weighed. The result will show the weight of the vessel, &c., emptied of air. Whilst still in the scale, the stopcock may be opened, and the vessel filled with air. The scale-pan will, of course, fall, and the amount of air, by weight in grains, is ascertained by adding weights to the other scale. A note of both these weights should be kept. Indeed, it is better to mark the weight in grains of the *exhausted* flask on the brass cap, which may easily be done by the scratch of a needle, without, in the least, interfering with any requisite accuracy by loss of weight through abrasion. Most instrument-makers keep such a globe in stock, that has been exhausted and weighed by them; and its volume, and the amount of air contained, is stated to the purchaser. It is desirable that the exhaustion and weighing should be repeated three or four times, and the average weight of the number may be taken as correct.

But there are other points of importance that must be attended to. At p. 569, *ante*, we have already pointed out that coal, and all other gases, are affected in their bulk by atmospheric pressure and temperature variations; and also by the comparative presence or absence of moisture. It is, therefore, necessary that certain standard points should be determined on, so that the observations of one person at different times, or of different persons at the same time, may be made to accord with each other. These are determined, by universal consent of philosophers, to be as follows:—The standard pressure of the barometer is settled at a height of 30 inches of the mercury; the standard temperature at 60° Fah.; and the standard of moisture, its complete absence—*i.e.*, the perfect dryness of the gas or air to be weighed.

But, practically, it is impossible to carry on, at all times, experiments with a gas to ascertain its specific gravity under such conditions; for the pressure, temperature, and moisture of the air or gas are constantly varying. It is hence necessary to make certain corrections; and although these are not so absolutely needful, to the same extent, for our purpose as they would be in purely philosophical research, still they must not be unheeded. The following method will afford sufficiently approximate results in ascertaining the specific gravity of coal-gas for ordinary purposes.

If 100 cubic inches of air, or any gas, were taken at a pressure of thirty inches of the barometer, it is evident that, as the volume is inversely as the pressure, a rise of the barometer would compress the 100 cubic inches into less space, whilst a fall of the barometer would expand the gas to a greater volume. It hence becomes a simple question of proportion to reduce any known bulk of gas to the standard of thirty inches of mercury. Thus, if at any moment a quantity of gas measured 100 cubic inches, with the barometer at twenty-nine inches, then, if the pressure were reduced to the standard of thirty inches, we should have the following proportion:—

30 : 29 :: 100 : x, the required number; or

$$x = \frac{29 \times 100}{30} = 96 \cdot 66.$$

That is, the 100 cubic inches, under a pressure of twenty-nine inches of the barometer, would only occupy the space of 96⅔ cubic inches under a pressure of thirty inches.

Of course, if the pressure were above thirty inches at the time of making the trial, the terms of the proportion would result in showing that the gas would occupy more space at the thirty inch pressure than at one higher than it; and so the quotient would come out higher than at the elevated pressure under which the gas was weighed.

For all practical purposes, in taking the specific gravity of coal-gas, the simple calculation given at a previous page will be sufficient, as regards correction for temperature. It is that of adding or deducting $\frac{1}{500}$th part of the bulk for an increase or decrease, respectively, for each degree above or below 60°. Unless the difference of the actual temperature be very great, which it is not likely to be under ordinary circumstances, the amount of error to the practical man is of no importance.

The correction for moisture is by no means so easily effected. It is usual, in determining the specific gravity of gases in a laboratory, to desiccate them; that is, to remove their moisture by passing them through strong sulphuric acid, or over fragments of fused chloride of calcium, both of which have so great an attraction for aqueous vapour as to rapidly remove it from the gases thus treated.

But one of these methods is absolutely impossible in respect to coal-gas; for if it be passed through sulphuric acid, the latter absorbs all the condensible hydrocarbons, and would render the attempt to ascertain the specific gravity of the gas futile, and the results absolutely erroneous and valueless; and it is by no means certain that passing the gas over the chloride of calcium might not have a decomposing effect on some of the ordinary constituents of coals—as, for example, the sulphuretted hydrogen, if much moisture were present. The only practically proper method with coal-gas, is to calculate the moisture according to the temperature; but the error in estimating the relative specific gravities of gas, ranging from low quality at 390, to higher quality—say from 600 to 700 as regards air, the standard—is so trifling as not to be worth the trouble for all purposes to which our directions are expected to be applied; and we shall, therefore, not occupy space with the description of the plan that must be adopted to attain the highest possible accuracy.

Returning to the practical part of the subject, we shall suppose that the weight of air that the glass vessel, represented by Fig. 430, contains is accurately known—we will suppose it to be thirty grains, which very nearly represents the weight of 100 cubic inches of atmospheric air (generally considered, however, to amount to about thirty-one grains). The vessel is now to be exhausted, by a syringe, of air as completely as possible; and when judged to be so, the stopcock is to be closed. It is then to be attached to a pipe conveying the coal-gas to be tested, which is allowed to run in and fill the vessel. This should thus be filled with, and exhausted of, gas three times, so as to ensure the entire removal of air; and the stopcock being closed, the vessel is to be removed from the supply-pipe. The globe should now be held with the stopcock downwards, and the latter is to be opened for a second or two of time, to allow an equalisation of the internal pressure of the gas with that of the external air; because, of course, the gas is forced in by a pressure of four or five inches of water, from the mains, greater than that of the external air.

This being done, the next step is to weigh the vessel thus filled with gas; and the ratio of its specific gravity to that of the air is at once ascertained by a simple calculation, as follows:—

If the quantity of gas that fills the glass vessel be but fifteen grains in weight, it is evident that its specific gravity can only be half that of air; for fifteen is but half of thirty. The specific gravity then would be, in reference to the air as the standard—

30 : 15 : : 1 : ·5; or

$$\frac{15 \cdot \times 1 \cdot}{30} = \cdot 5$$

Hence the specific gravity of the gas would be ·5. A more difficult example to the tyro will be as follows. On weighing the gas, it was found to amount to twenty-seven grains. Then—

30, the weight of air, is to
27, ,, ,, gas, as
1 is to the specific gravity of the gas; or
30 : 27 : : 1 : x, the specific gravity of the gas.

$$\text{Therefore } x = \frac{27 \times 1}{30} = \cdot 9$$

Here the specific gravity comes out as ·9; or, assuming (which is the same thing) that air = 1,000, as we have done in the preceding pages, then the specific gravity of the gas is 900, which is about equal to that of oil-gas, as shown at a previous page.

Although we have thought it right to speak of, and give directions for, the correction due to pressure and temperature, they may be rendered unnecessary if the operator ascertains, by exhausting and weighing the glass vessel, what amount of air in weight, *at that moment*, it may contain. As the pressure and temperature cannot, under any ordinary circumstances, vary to any extent in a few minutes, he may next proceed as directed for weighing the gas, and calculate from the results, by the method just directed, the specific gravity of the latter. It will be at once seen, that as the weighings are carried on immediately after each other, questions of temperature and pressure may be neglected for comparative trials. If, however, the results are to be compared with others, of and under different atmospheric conditions, then the corrections become absolutely requisite.

The other physical method to which we alluded, as a test of the commercial value of coal-gas, is

that known as photometry; and although we have already described the leading principles on which the method is founded, we may here again briefly allude to them, the repetition being in part necessary to make our present remarks understood.

Light emanating from any luminous object rapidly diminishes in its intensity. Supposing, for example, that at a distance of two feet from its source it may be considered at any normal amount of intensity, at four feet it will be reduced to one-fourth of that intensity; at six feet, to one-ninth; and so the measure of the decrease or decrement is the reciprocal of the square of the distance—thus $2 \times 2 = 4$, the square of 2, the reciprocal of which is $\frac{1}{4}$th—at six feet the light would be three times two feet distance, or $3 \times 3 = 9$, the square of 3, the reciprocal of which is $\frac{1}{9}$. Thus, for any chosen distance, the same rule goes on.

Two lights may therefore be readily compared with each other as regards their intensity; for if one gives an equal light or shadow at double the distance of the other, it is evident that their intensity, according to the above laws, must be as the squares of their respective distances. Experimentally this is easily proved by so arranging a screen, receiving the light from two luminous objects, that the shadow they individually cast shall be of equal intensity. Now, if the separate distance of each of the luminous objects be measured and squared, their relatively illuminating power will be ascertained.

Instruments called photometers have been arranged for this purpose, of various kinds and forms, all dependent on the above-mentioned principle. But that chiefly preferred is Bunsen's, from its simplicity and ease of use.

The following description of its construction, by an eminent writer on gas matters, will convey an idea of its construction and use:—

"It will be noticed that if a piece of white filtering-paper is painted over with melted wax, or spermaceti, it acquires a greasy appearance, and becomes translucent: if this be done so as to leave a spot or disc, about the size of a shilling, untouched in the centre of the paper, we shall find that the apparatus will have the following properties:—When examined by reflected light—that is, with the light on the same side of the paper as the observer is—the disc will look white, and the surrounding greasy part dark; but by altering this condition of things, and looking at the paper by transmitted light—that is, with the light on the opposite side of the instrument—the disc will appear dark, and the surrounding greasy portion light and translucent. Lastly, if two lights, of equal intensity, are placed on each side of the paper, the disc will disappear entirely; for then the light of one side neutralises that of the other, and there is no disposition to produce either effect. Upon this is founded the principle of Bunsen's photometer. This instrument consists of a graduated rod, about five feet in length, having a support at each end. The prepared paper is held by a frame, which slides upon the rod, between the lights. This frame is usually enclosed in a darkened chamber, so as to exclude all light but that emanating from the object to be tested. The frame containing the paper is slid to one side or the other until the disc entirely disappears, and thus we read off the value of the two lights."

It will thus be seen that the photometric method of determining the commercial value of gas is entirely of a physical character, and dependent for its operation on the laws of radial forces decreasing in proportion to the square of the distance of the illuminated from the illuminating body.

We have already noticed that a certain standard has been agreed on, to which all photometric results are referred. It is that of the burning of a sperm candle, six to the pound, and consuming the material at the rate of 120 grains per hour.

It would naturally be supposed that this method, at least, would be characterised by accuracy; but such is by no means the case. Of course, in testing the value of gas, a definite-sized burner must be employed; and, in respect to the London gas-supply, the act of parliament requires that an Argand burner shall be used, have its rim pierced with sixteen holes, and consuming the gas at the rate of five cubic feet per hour. But all gases will not burn equally well, so as to exhibit the full intensity of light in this form of burner. In some cases the results obtained are highly discrepant; and hence many errors may be made in determining the candle value of various gases by such means. Some gases give their maximum of light better, with the same amount of consumption of gas, with other forms of burners, as the fish-tail or bat's-wing, especially such gases as are highly hydrocarbonous; for example, those obtained from varieties of cannel coal.

Another source of error arises in respect to the amount of gas consumed in a set time. We have already pointed out that variations of barometric pressure and of temperature affect the burning of gas, causing an increase or decrease of its illuminating power. The following, quoted from the authority last referred to, illustrates this fact in a striking manner. The table gives the quantity of gas consumed per hour by an Argand burner with seventy-two holes; and, at the same time, the relative candle value of each flame; by which it will be perceived that alteration in the amount of gas consumed greatly affects the photometric results.

Burner.	Consumption per hour in cubic feet.	Power of gas per foot.
Argand with seventy-two holes	7·0	5·57
	5·0	6·60
	3·3	3·40

Having thus examined the two physical methods of ascertaining the candle value of gas, it is evident that neither supply us with means of arriving at an absolute degree of accuracy. But this need be no matter of surprise, when we bear in mind the varying quality of gas in respect to its hydrocarbons, and the consequent con-

ditions it imposes on all attempts such as we have described, and have yet to allude to.

We next turn to some of the chemical methods that have been recommended, and which depend for their *quantum valeat* amount of success on many circumstances.

One plan is that of absorbing the hydrocarbons of the gas, and of judging, by the extent of that absorption, its comparative value ; for, of course, the more the loss from such absorption, the greater the illuminating power of the gas, for on them this quality depends. Chlorine, bromine, and sulphuric acid, have all been employed for this purpose. Sulphuric acid only incompletely absorbs, taking some, and not acting on others. The mode of using either chlorine or bromine is generally similar. The chlorine gas, or the bromine, as a liquid, is passed into a tube containing the gas to be tested. If chlorine be used the tube must be shaded from the light, because of the energetic combination that would take place between the chlorine and the hydrogen under such circumstances. When it is judged that the absorption by either is completed, the excess of those elements is absorbed by passing in potash, and the loss which the gas has undergone becomes a measure of its value. The greater the loss, which varies from 3 to 20 per cent., the richer the gas in illuminating power.

The eudiometric method has also been proposed and adopted. It depends for its success on the fact, that the more oxygen a gas requires for its complete combustion, the richer it must be in hydrocarbons. The eudiometer is a graduated glass instrument, so arranged that it may be filled with a mixture of oxygen and gases inflammable with it. The mixture being exploded by means of an electric spark, or, if much hydrogen be present, by introducing spongy platina, affords its results by the production of water and carbonic acid, the latter being afterwards absorbed by potass, the increase in the weight of which, of course, gives the quantity of the acid produced ; and from the composition of this, which is one equivalent of carbon to two of oxygen, the quantity of hydrocarbons may be estimated.

The annexed cut illustrates one form of the

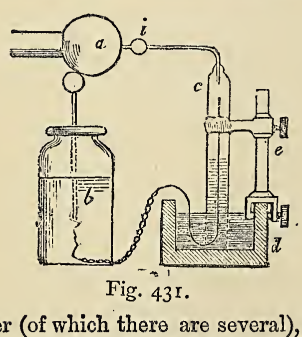


Fig. 431.

eudiometer (of which there are several), and the mode of use when electricity is employed to ignite the mixed gases. *c* represents the top of the graduated glass vessel, in which is inserted air-tight, by heat, a piece of platinum wire, which terminates by a knob, *i*, that faces the prime conductor of an electrical machine. The ball of a Leyden jar, *b*, connected by means of a wire and chain with the inside of the jar, is placed in close proximity to *a*, the knob of the electrical machine conductor. *d* is a pneumatic trough, filled with mercury ; and a chain extends outside of the Leyden jar, so as to be in contact with the mercury of the trough, and also attached to a wire that passes up the centre of *c*, and nearly, but not quite, touches the platinum wire inserted at its top.

The gases being introduced into *c*—that is, the coal-gas and oxygen—the electrical machine is worked so as to charge *b*. On this being completed, a spark will pass from the knob of the machine, *a*, to *i*, one terminal of the platina. Instantly reaching the other terminal at *c*, inside the eudiometer, it will pass to the wire extending upwards, and thus the gases will be exploded. *e* is merely an upright support to hold the tube in a vertical position, and to prevent its leaping out of the trough by the violence of the explosion. In ordinarily using the eudiometer, the jar alone is sufficient, when charged, to ignite the gases.

The value of this method depends on its showing the relative proportions of carbon present ; and the richer the hydrocarbons in the gas, the greater will be the amount of oxygen consumed. Thus the following table shows the result of such a method, and also the composition of each gas :—

One volume of	Oxygen required to burn.	Carbonic Acid produced.
$C\,H_2$, marsh gas, or light carburetted hydrogen	2·0	1
$C_4\,H_4$, or $C_2\,H_2$, olefiant gas	3·0	2
$C_6\,H_6$, super-olefiant gas	4·5	3
$C_8\,H_8$, Faraday's gas	6·0	4
$C_6\,H_3$, bicarburetted hydrogen	7·5	6

Hence, the richer the gas is in hydrocarbons, the more oxygen is consumed in the eudiometer, and the larger the quantity of carbonic acid afforded.

Numerous other methods have been proposed for the analysis of coal-gas; but, as previously stated, we are not aware of any that can alone be depended on. At the present time, the chief points for determination, in respect to the reports of the officers appointed to inspect the gas supply, are the candle value of the gas, and the amount of sulphur present. In respect to both these abundant information has been given in the preceding pages ; and their value may be judged of by reference to the reports of the quality of London gas, as frequently published in the daily and other papers.

In the following table, for which we are indebted to the investigations of Dr. Letheby, Mr. Lewis Thompson, and Mr. Evans, several valuable results and facts are recorded. At the same time there is little doubt that the first column gives, by 10 or 12 per cent., too high a value for the gas-producing power of all the

coals. The results in these respects, already afforded in this work, derived from the latest recorded experiments or observations, on the largest possible scale, are much more trustworthy. But, *inter se*, and with the deduction just suggested for the first column, the table is of much utility.

Table of the Produce per Ton of Coals in Gas, its Illuminating Power, &c.

Coals.	Cubic feet of gas per ton.	Illuminating power.	Specific gravity.	Condens. by Bromine.	Value in grains of Sperm.
Boghead cannel......	15,000	37·75	752	30·0	113,250
Lesmahago, No. 1...	13,500	27·10	642	16·0	73,170
Wemyss	14,300	24·50	580	14·0	70,070
Lesmahago, No. 2...	13,200	24·80	618	17·0	65,472
Capeldrae	14,400	19·75	577	16·5	56,880
Armiston	12,600	22·50	626	17·0	56,600
Kirkness	12,800	21·20	562	10·2	54,272
Knightswood.........	12,200	19·00	550	9·5	50,160
Wigan (Ince Hall)	11,400	20·00	528	11·5	45,600
Ramsay	10,300	21·40	548	12·5	44,084
Pelton cannel.........	11,500	18·50	520	10·5	42,750
Leverson cannel ...	11,600	18·00	525	10·0	41,720
Washington cannel	10,500	18·00	500	10·5	37,800
Brymbo main.........	10,500	15·00	540	6·8	31,500
Pelton main	11,000	14·00	430	4·5	30,800
Dean's Primrose ...	10,500	12·00	430	5·0	28,350
Washington	10,000	14·00	430	5·0	28,000
Pelaw	11,000	12·75	420	4·5	28,050
Brymbo cannel	6,650	20·00	504	11·5	27,160
Blenkinsopp	9,700	14·00	450	6·0	27,160
Leverson	10,800	12·50	425	4·0	27,000
West Hartley.........	10,500	12·50	420	4·2	26,250
Hasting's Hartley...	10,300	12·50	421	4·3	25,750
New Pelton............	10,500	12·00	415	4·8	25,200
Garefield...............	10,500	11·50	398	3·8	24,150
Gosforth	10,000	12·00	402	4·0	24,000

We may now dismiss the subject of the gas manufacture, so far as its appliances, chemical processes, or production, purification, distribution, residual products, analysis, &c., are concerned, and pass on to describe the best method of its combustion, the mechanical contrivances that have been adopted for its measurement, and the regulation of its supply; the ventilation that should at all times be carried out in rooms, or other enclosed places, in which gas is found; and add some remarks, also, in regard to gas explosions.

Whilst the subjects that have hitherto come under notice have been, with the exception of the general description of the processes, mostly of interest to those who are engaged in the manufacture at the gas-house, or as professionally concerned in analysing gas so produced, our future pages will contain matter of much more universal interest, as appealing to the daily experience and requirements of all those who use gas, or may propose to do so.

At the present time, the consumption of gas, although so large, is considerably less than its advantages and conveniences recommend. With but moderate attention and care, it is very much safer than any other mode of artificial light. It clearly produces nothing that need at all disturb or spoil the neatness or elegance of the best-furnished apartment, provided due ventilation be adopted. It has not the disadvantage of throwing off sparks—so common a cause, when gas was less used, of extensive and fatal fires. It is readily under control, by means of a main tap, which should always be situated in a position of easy access, together with the meter, so that in case of accidental escape the supply might be instantly cut off.

Into these subjects, however, we shall next enter more at large in connection with the details of gas management generally by the consumer, earnestly hoping that the hints which may be given will prove of service in diminishing every objection to the use of gas in respect to its danger, that may, and always will, exist in the absence of proper fittings and due care.

The contemplation of our present water and light supply, together with that of the invention and extensive applications of the electric telegraph, may well make every student and lover of science proud of its pursuit. Our streets are underlaid with thousands of miles of pipes and wires, all essential, not only to the comfort of the inhabitants of our towns, but equally so to the very existence of the inhabitants. We cannot help feeling some wonder as to how our forefathers could struggle through life without such arrangements; and yet, fifty years ago, there were neither gas-pipes nor telegraph wires; and the water-supply then was a monopoly confined to a few companies, reaping enormous profits, and charging outrageous prices. All the changes to which we have alluded have occurred within the times of a large proportion of the living; and the circumstances that preceded these changes are rapidly becoming matters—we had almost said of ancient history—so quickly do new improvements eclipse the memory of old contrivances. But even the circumstances of our day are rapidly undergoing change; and the wonderful inventions that we are now constantly adopting in general use, will soon have to give way for fresh improvements, at present unknown, and only dimly seen in the distance. A use of gas to which we have already alluded, and which has been the subject of remark, at p. 606, belongs to this category of advancement. We refer to its employment as a motive power, which has already been adopted to a far greater extent, since its first practical success was shown possible, than was the steam-engine of Watt for a period of much longer time. In fact, the general tendency of mankind is to utilise everything; and if ever there was a time when it might be truthfully said that man had sought out many inventions, surely the nineteenth century may claim it as characteristic of its condition and progress.

Consumption, Etc., of Gas.

The consumption of gas is a subject of such familiar interest to most of our readers, as to require, in its practical detail at least, apparently trifling remark. At the present time, there are certain almost universal forms of gas-burners that need scarcely a description, from their general use; and these are chosen so much according to the fancy of the consumer, that

any remarks on the subject will necessarily be received with a great degree of allowance.

At the same time science is greatly involved in the question, because the proper or economical consumption of gas essentially depends on scientific principles. If, for example, a gas-burner of any particular kind is used to burn a high or low carbonous gas, the results of the combustion, in respect to the amount of light afforded, will greatly vary. This is a question that has been already discussed at p. 617, *ante*, and therefore scarcely needs further elucidation.

The simplest form of gas-combustion is evidently that in which, like the old-fashioned oil-lamp, a single flame is afforded. This must necessarily be hollow internally; and if the quantity of gas burnt be beyond the capacity of the burner, a large amount will be wasted, owing to imperfect combustion. The ordinary external flaring lights of the butchers', greengrocers', and other such shops, are instances of this kind. The single-jet form of gas-burning is generally confined to the purposes of *fêtes*, and other illuminating objects of a similar kind: it is but rarely, if ever, employed in domestic use.

The Argand burner we have already frequently referred to in the preceding pages. It is especially characterised by admitting air on both sides of the flame; that is, on its exterior and interior: consequently, no matter what fuel is used—tallow, oil, or gas—a kind of double combustion goes on; the flame of the wick becoming practically flat, and therefore the action of the atmospheric oxygen, in promoting combustion, is extremely great.

Fish-tail and bat's-wing burners have an analogous action, because the flame is made flat, and destitute of "hollowness:" consequently, the hydrocarbons of the gas are freely exposed, during combustion, to the oxygen of the air; and therefore these forms of burners are extremely advantageous to the consumers, and, generally speaking, are far more economical than any other form.

But, in every mode of gas-combustion, much depends on the regulation of the amount of gas supplied. If this be deficient, of course the "light" will be too dim. On the other hand, if the gas be too fully supplied—that is, if the tap or stopcock be full open at a time of great pressure at the main (for example, at dusk, when the pressure at the gas-house is increased, so as to meet the sudden demand of incipient darkness)—then, not only does the gas undergo over-combustion, but a portion will escape without being burnt.

It would hence appear, that, despite the faults and sins of gas companies, the consumers have much to answer for; because the regulation of the amount of gas, and, consequently, of the amount of light, depend on the latter. Hence many of the complaints, at paying-time, of over-registration in respect to meters, of which we shall have to speak more fully hereafter.

An authority that we have already quoted, and pointedly alluded to as one of the most reliable of the present day, observes—"Scarcely anything connected with the subject of gas illumination has commanded more attention than the means whereby gas may be burnt to the best advantage; and although the greatest ingenuity has been displayed in the construction of many of the burners which, at different times, have been invented, yet none of them possesses that universal applicability for which they have been so highly vaunted. The reason of this is obvious: different kinds of gas require different forms of burners in order to effect perfect combustion. As a rule, it may be stated, that the rich cannel gases are best consumed from burners with very fine apertures; while the poorer gases—namely, those which contain less than 5 or 6 per cent. of condensible hydrocarbons—are burnt with most advantage with large apertures. Again, in the former case, provision should be made for a large supply of atmospheric air, as by spreading out the flame by means of an internal button, or by using tall glasses; whereas, in the latter case, the very opposite condition should be observed. It is manifest, therefore, that no single burner can be constructed so as to secure both of these requirements; and, consequently, that any burner which is well suited for one kind of gas, is altogether unfit for another.

"Another point of importance to which we may refer, in speaking of this subject, is the following:—That, when several jets issue from the same burner, and blend together, or coalesce, the light is always improved; for it is the property of one jet to assist another by exalting its temperature; and thus a greater heat, and a brighter flame, are the result of this union—more light being given out than is the sum of the individual jets. It is on this account that the Argand burner, the fish-tail, and other analogous burners, have obtained preference over many other forms.

"Lastly, it may be stated that, in whatever way gas is consumed, the maximum effect, as regards the illuminating power, is always produced by burning the gas just short of its smoking-point; for, if it be burnt with too much air, the particles of carbon are over-consumed; and we thus obtain a diminishing light until the flame is of a pale-blue colour. On the other hand, if it be burnt with too small a supply of atmospheric air, the particles of carbon will not be sufficiently consumed, and they will escape as soot, thereby cooling the flame, and making it of a dingy yellow tint. Our object, therefore, should always be to burn the gas in such a manner that the particles of carbon may be first intensely heated, so as to produce a white light; and then, as they reach the exterior of the flame, they ought to be consumed entirely, so as to avoid the evolution of soot."

The preceding quotation, of judicious remarks by an eminent authority, will commend itself to all our readers who are consumers of gas. Practically, every one is acquainted with the fact, that, with any burner employed, there is a comparatively narrow limit within which a maximum

and minimum of light are afforded; but the practical result of the foregoing remarks, amounts to a recommendation of the use of such special forms of burners as are solely suitable to certain kinds of gas. Thus, in London, a well-arranged Argand burner seems to be most advisable; whilst, in Wigan, Glasgow, Edinburgh, and other cannel coal districts, the bat's-wing or fish-tail is the most advisable. Whether by design, science, or accident, we have generally found such an idea carried out in practice.

But, after all, the economical burning of gas—that is, the obtaining the largest amount of light with the least expenditure of material—depends on other circumstances than those of the burner. The variation of pressure in the main, of atmospheric pressure, temperature and moisture (already referred to at p. 569, *ante*), and many other conditions, of an accidental nature, render it imposible to give exact directions on this point; hence much must be left to the discretion of those who use gas as an illuminating agent.

The usually employed burners, at the present day, are chiefly the fish-tail, bat's-wing, modified Argand, and sun or star-light. The fish-tail produces its flame by the direction of two jets against each other, the holes in the jet being drilled at an angle of about 60°. The flame of each thus coalesces; and, whilst forming a flame of the fish-tail form, it is so flattened, or narrowed, as to expose a large surface of gas to the action of the oxygen of the atmosphere.

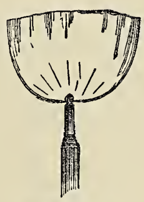


Fig. 432.

The bat's-wing jet similarly derives its name from the form of the flame it produces; and is formed by making a slit in the burner in place of two holes, as in the fish-tail. Both forms of burner are economical in use, generally producing as much light, according to the size of the holes or slit, by the combustion of three or four cubic feet of gas per hour, as the Argand, consuming about five feet. The annexed cut represents the form of the bat's-wing flame.

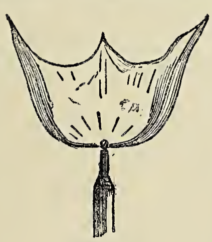


Fig. 433.

In respect to the Argand burner, so many modifications have been introduced, that it would be difficult to give illustrations of them. One of the best we have seen, *if properly regulated*, is Leslie's. In this, the principle of dividing the flame into a number of separate jets is adopted. For this purpose, a series of small tubes are employed, as shown in Fig. 434, each converging towards the centre or axis of all the flames. These burners require a rich gas for their most economical use. We have seen several hundred simultaneously burning, and affording an excellent, pure, and white light under such circumstances. But if an inferior gas be employed, the principle of their construction is such, that they cause a diminution of light, owing to over-combustion. There is also the occasional inconvenience of the tubes becoming stopped up—a fault arising more from the impurities of the gas supply than from the construction of the burner, which then becomes useless.

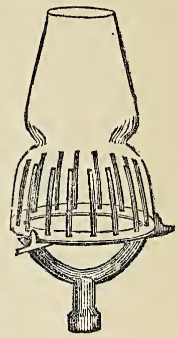


Fig. 434.

It would be impossible, as already explained, to assign the right of superiority to any form of burner, especially on account of the varying hydrocarbonous character of gas, and the alternations of the pressure. "Dr. Letheby states, in his ninth report to the corporation of London, that gas ought to be delivered to the consumer at not less than half an inch of water present; and it may be said that this is found to be the best pressure at which gas can be consumed. * * * It is also a matter of importance, that the pressure at which gas is supplied to the burner should be as uniform as possible; for if, at one time, the pressure be great, and at another low, the burner will require constant attention, in order that the flame shall be of uniform height."

In respect to this point, we may observe that many regulators or governors have been invented, most of which have been recommended as economising the use of gas by controlling the pressure at which it is consumed. We have seen, tried, and reported on many; but are forced to the conviction that all fail to carry out completely the objects for which they are constructed. Gaseous bodies are of far too high a tenuity to allow of exact management. Even in the hands of the experienced chemist they are difficult to deal with; and, such being the case, it is no matter of surprise that those less acquainted with scientific principles should fail. We have already alluded to the general principle of governors at a previous page. They are all constructed on the principle of what we may call *obstruction;* that is, rendering the free flow of gas, under higher than proper pressure, more or less difficult. Now it is evident that such a condition of regulation cannot be uniform as a matter of reason; and as a matter of practice, the failure is too well known.

Of late years, the sun or star-light form of burner has been much used for lighting large buildings. It consists of a number of burners fixed at the ends of pipes, radiating horizontally from a perpendicular supply-pipe; the number of jets being regulated according to the light requirements of the hall, &c. The combination of burners is fixed a little below the ceiling, and covered with a kind of dome. Through or over this the hot air caused by the combustion is carried off, and thus the apartment may be lighted and ventilated simultaneously. A great

advantage of this mode of lighting arises from the fact, that the light is above, and far beyond the heads of an audience; and, consequently, the unpleasant glare of side lights is avoided.

In respect to the question of pressure at which gas is burnt economically, Dr. Fyfe has also added the condition of specific gravity. He observes, "that there are certain constant relations between the specific gravity of a gas—that is, equivalent to its goodness [see *ante*, p. 616]—and the presssure at which it is burnt, and the time required to consume it; that is, provided we use a jet of given size, and take care that the flame is of a given height. The jet he prefers is one having a hole of $\frac{1}{40}$th of an inch in diameter, and the height of the flame should be five inches. These relations are as follow:—

"1st. The consumption of gas, in a given time, is as the square root of the pressure; and, consequently, the time required for the consumption of equal volumes is inversely as the square root of the pressure.

"2nd. The specific gravity of the gas is also inversely as the square root of the pressure.

"So that if we determine, by experiment, what time it takes for a given volume of gas, of known specific gravity, to burn from a jet of the given size, with a flame of the given height, we are in a condition to tell the specific gravity, or rate of consumption, of any other gas, provided it be burnt under the same circumstances, and we observe the pressure. This will be manifest from the following table:—

Pressure, in inches, of water.	Consumption per hour.	Specific gravity.
0·6	0·67	·841
0·7	0·72	·779
0·8	0·77	·729
0·9	0·81	·687
1·0	0·86	·652
1·1	0·90	·622
1·2	0·94	·595
1·3	0·98	·572
1·4	1·02	·551
1·5	1·05	·532
1·6	1·09	·515
1·7	1·12	·500
1·8	1·15	·486
1·9	1·18	·472
2·0	1·21	·461

"By means of this table we are able to determine the rate at which gas is burning, or its specific gravity, by merely observing the pressure which is necessary to attain a flame of the given height. In conducting the experiment, the pressure gauge must, of course, be on the jet side of the tap. Dr. Fyfe suggests that we may, by operating in this manner, do away with the necessity for a meter or photometer, or both; and that we may arrive at results which are approximately correct. Of course, it must be understood that the gas is of the usual quality, and free from carbonic acid and atmospheric air."

The pressure gauge is an extremely simple contrivance; and is represented in the cut Fig. 435. It consists of a glass tube bent into a syphon form, in which, so long as the pressure of the gas is only equal to that of the atmosphere, the coloured water in it will be of the same level in each leg. But, as in the cut, if the pressure of the gas be greater than the atmospheric, then supposing A to be inserted in the supply-pipe, the gas will force the liquid down at B, causing its uprise at C; and the difference of level of these two points, by means of simple inch graduation, indicates the pressure, in inches of the distilled water, at which the gas is either supplied or consumed.

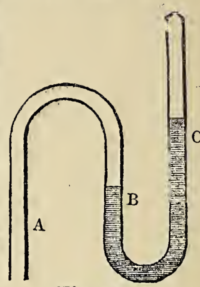


Fig. 435.

Practically, however, all scientific questions are entirely ignored, so far as the consumer is concerned. All he requires is a "good light;" that is, one that illuminates the shop, church, hall, or house; and having, or believing himself to have, a proper burner, he regulates the light either by the meter-tap, in the case of large consumption, or by means of the burner-tap, in respect to house-supply. As already stated, we have little faith in the actual value of any of the gas governors that have been invented. Some certainly act extremely well; but, on the average, they require an amount of governance for the purpose of avoiding which they are sold.

Of recent years, it has been re-discovered (for, as we have shown at p. 552, *ante*, the ancients seem to have been acquainted with the fact), that metal, but especially thick metal burners, abstract a large proportion of the heat which is essential to the proper combustion of gas; hence earthen burners have been adopted in numerous instances, and with great success. The principle is precisely that which recommends the common-sense or scientific use of earthen "backs" in fire-grates; and depends on the non-conducting power, in respect to heat, in both cases. Accordingly, silicious material has, to some extent, superseded iron in the construction, at least, of the bat's-wing and fish-tail form of burners.

We next turn to the meter—a most important element in gas consumption, and one that entirely regulates the contract between the consumer and the gas company. At one time, gas was burnt by the consumer at so much a year for each burner—not as a universal rule; but, at the same time, the arrangement was of common occurrence. Of course, such a plan was always one that raised disputes, and, consequently, discouraged the use of gas. It was fair to neither party.

Mr. Clegg was the first to suggest a method by which a measurement of the gas consumed could be effected. In 1815 he constructed the first meter. In the following year he obtained a patent for his invention. "At first, Mr. Clegg attempted to register the gas by means of two small gasometers, which rose and fell alternately, one receiving the gas while the other was delivering it. But this plan was not suc-

cessful, and was abandoned for another, which constitutes the basis of all the wet meters that have been contrived since Mr. Clegg's time. It consisted of a drum, which revolved in a chamber half filled with water. The drum was divided into two compartments, one of which received the gas, while the other delivered it. The gas entered through the hollow axis of the instrument; and as the drum revolved and submersed in the compartment, the gas was forced through a lateral opening into the outer chamber, and thence to the burners. By means of valvular contrivances, two of which were closed by water, and two by springs, the gas was made to flow only in one direction; but as the spring-valves were easily thrown out of order, and the water-valves were of a clumsy form, the instrument was open to very great improvement. Mr. Malam, therefore, in 1819, reconstructed the apparatus. He divided the drum into five compartments—one of which was central, and the others around it [as shown in Fig. 436]. As

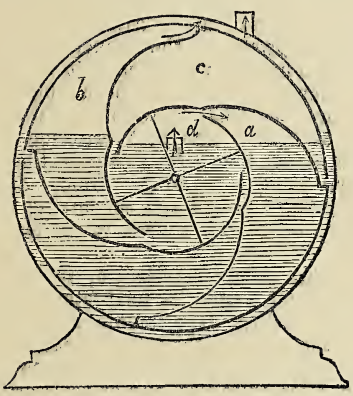


Fig. 436.—The Water Gas-meter.

in Mr. Clegg's instrument, the gas entered the apparatus through the axis of the drum; but in order that there should be no friction or impediment to its movement, he did away with the stuffing-box in which it worked, and brought the central tube or axis, by means of a rectangular bend, up above the level of the water in the central chamber [as shown at *d* in the preceding cut]. He also put aside the clumsy water-valves, and the two delicate spring-valves of Clegg's instrument; and adopted a simple contrivance, whereby the delivering apertures were made to act of themselves. These apertures were in the form of slits, which communicated first between the central chamber and the circumferential ones, and then between the latter and the outer case. On entering the central compartment, the gas escapes through whichever of the first set of slits happens to be above the level of the water. In the preceding cut, it is passing from *d* to *a*. This gives a buoyancy to that chamber; and, as it rises or floats, it turns the drum round from right to left, causing the gas, which is in the upper and descending compartments, to escape through these outer slits into the outer chamber, and thence to the burner. It will be noticed, that, as the drum revolves, the entrance-slits, between the middle and outer chambers, are successively carried under the water; and that, as soon as this happens, the exit-slits in the circumference of the drum are each, in their turn, brought out of it. This is shown, in the preceding figure, as about to occur with compartment *c*, whose entrance-slit is just dipping under the water, while the exit-slit is rising out of it."

Gradually, many improvements were effected in respect to the water meter; and it thus became a more complete, although still imperfect, instrument. The annexed cut represents a usual form of

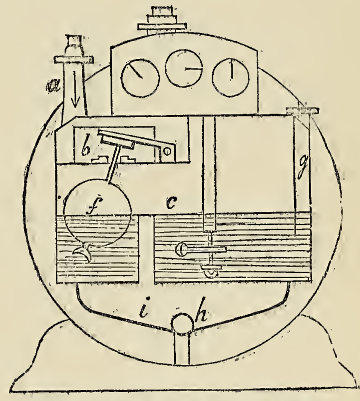


Fig. 437.—The Water Gas-meter.

water meter, in which *a* shows the passage by which the gas enters the meter from the main into the chamber *b*; whence it passes, by a flat valve, to *c*. Thence it proceeds through a bent pipe, forming the axle of the drum, into *d* (see also next cut, in which the letters correspond with the above). Entering one of the departments already referred to, it escapes by an exit-slit into the exterior case. *f* is a ball floating in the water, and keeping the flat valve, above mentioned, open. This ball regulates the passage of the gas in relation to the level of the water; and if the latter be too low, it shuts off the supply of gas. *g* is a tube by which water can be added when the meter ceases to act from a deficiency of that fluid. *h* is a syphon tube for drawing off an excess of water that passes into the chamber *i*, that acts as a cistern to receive such excess. The revolution of the drum acts on indexes, that thus register, in tens, hundreds, thousands, &c., the amount of gas passing in cubic feet through the meter. This is effected by a simple arrangement of clock-work.

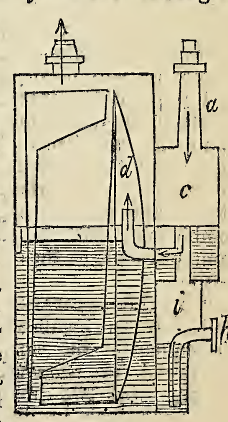


Fig. 438.

The preceding description is that of what is called a water or wet meter; but this is subject to several objections. In the first place, its registration is not to be depended on for exactness; next, a deficiency of water is often followed by an instant and inconvenient extinction of all the lights attached to it. In winter the water might freeze; and, consequently, not only would the operation of it be prevented, but, of course, no gas could be got through it for illuminating purposes. In many ways it may be made an instrument of fraud on the part of the consumer and the gas company; so that either or both, by a simple disturbance of its position, or the amount of water present, may gain or lose.

The dry meter has, therefore, been largely, and almost entirely, substituted for the wet one. The general construction of dry meters may be explained as that resembling a pair of bellows alternately filled and emptied of gas, each filling being registered by clock-work, the pointers of the dial-plate indicating, as in the wet meter, the number of feet consumed. "The first dry meter was patented by Mr. Malam in 1820: it consisted of a set of six bellows placed in a radiating direction around a common centre, the whole being enclosed in an air-tight chamber. These bellows worked successively the one after the other, and they communicated their motion to a set of wheels [by clock-work] that served to register the quantity of gas delivered." Gradually, improvements were made on this elementary form of gas meter; and, without entering into purely mechanical details that would be apart from our purpose to describe, it may be added, that the present mode of registering the consumption of gas by the dry meter, is, on an average, very little short of accuracy. Of this kind are the modern meters, especially as made by Croll, Defries, and others.

Some years ago, a very ingenious form of meter, devised by Mr. Clegg, and called the differential dry gas-light meter, was introduced. We are not aware how far it was generally adopted, and have not seen one in operation. To many of our practical readers, however, the following extracts from a paper by Professor Vignolles, will be of some interest. Speaking of its qualities generally, he remarks—"The construction and action of this meter are based upon the established fact that the heat and light from the various kinds of carburetted hydrogen gas, are strictly proportionate to each other; and on the application of that fact, in combination with an apparatus, acting on the same principle as the differential thermometer of Leslie.

"By this apparatus may be measured, most delicately, the smallest differences of heat; and, consequently, the consumption of gas may be registered in proportion to its illuminating power. Let two hollow glass cylinders, each about one inch in diameter, and three inches long, be connected together, in the centre of their lengths, by a hollow bent tube of the same material. * * * Let this cylinder and the connecting tube be perfectly exhausted of air, and let as much alcohol be introduced as will nearly fill one cylinder, leaving a vacuum in the other, or, at least, leaving it without air, and with only such vapour therein as may arise from the alcohol. Now, as pure alcohol boils, *in vacuo*, at 56° Fah., the smallest excess of heat above this temperature, applied to the cylinder having the alcohol, will cause the liquid to evaporate, and, by its consequent elasticity, will drive the spirit below the vapour into the colder cylinder; and the velocity with which the alcohol will be driven out from one cylinder to the other, will be in exact proportion to the quantity of heat applied—twice or three times the cause, producing twice or three times the effect, and so on. For, let air or gas be heated to a uniform temperature—say 150° Fah.—and, when so heated, let it be directed to impinge upon one of the glass cylinders, such as those above described, with any given velocity; if this velocity be doubled, then double the quantity, or volume, or body of heat will be passed, and, consequently, double the effect—that is, double the velocity with which the alcohol is driven—must be produced, such being an unerring and natural law. Although twice the effect be thus produced, the temperature of the air or gas has not been increased—it is only the flow or quantity which has been augmented; and this must be what is to be understood by quantity of heat. The best criterion of the soundness of the above statement is, that these facts have been determined from, and are founded upon, repeated and concurring experiments—the only true source of philosophical induction.

"Such then being established, it became a leading principle; and the next step was to ascertain, by further experiments, how to apply this scientific fact to the art of measuring the quantity of heat applied to one of the above-described glass cylinders, and of registering the same; for, this being accomplished, there was at once obtained an apparatus, whereby may be determined the exact flow of air or gas in a given time; in other words, a gas-light meter such as the present instrument. The first consideration, therefore, was, how to heat a given quantity of gas to a certain uniform temperature; for the gas being thus heated, and allowed to flow out at a given velocity, a uniform flow of heat was obtained.

"Now, for the purpose of measuring this flow of heat, in the instance of a gas meter, the source of heat is present by the inflammable gas itself; and after numerous experiments, it was fully and conclusively ascertained, that a jet of gas issuing out of an orifice perforated in the side of a small solid brass cylinder, * * * will heat the said cylinder to a uniform given temperature, whatever be the height of the said jet; for a small flame, the jet clings as it were, and is in immediate contact with the solid cylinder; whereas, when the flame issues from the orifice with considerable velocity, still the longer jet only imparts the same degree of heat to the solid cylinder as did the smaller one; the increased or lengthened flame being, in this latter case, driven away from any closer contact by its

own velocity, or rather by the velocity due to the pressure of the gas issuing from its orifice. This fact having been thoroughly established by repeated experiments and practice, the necessary apparatus of the gas meter for the practical application of the fact became very simple.

"The next point expedient to be determined accurately, was the proper superficies of a receptacle, to be heated by or from such a solid cylinder as the one just described; which surface would be sufficient to communicate the requisite heat to such portion of the whole gas to be measured as it was necessary to pass through the receptacle, without altering the temperature thereof in any perceptible degree. This point was ascertained, as the preceding ones were, by repeated experiments; and, further, it was found advisable that the receptacle for heating the gas should be well clothed with the best non-conducting substance, to keep it at a proper temperature. The proportionate surface of the receptacle having been determined, certain other proportions and dimensions were established.

* * * * * *

"Lastly, it remained to be found what quantity of gas, heated in the manner previously described, and discharged upon one of two such glass cylinders as before mentioned, would be sufficient to expel the alcohol therefrom, and drive it into the other cylinder. Numerous experiments and long practice have determined this quantity to be no more than about one-seventh part of the whole gas requisite to supply the number of burners, the consumption whereof is to be measured.

"This being conclusively established, led to the consequent arrangement of dividing the flow of gas, as supplied from the main, so as to pass them separately through two openings; one of which should have its area six times that of the other, whereby six-sevenths of the gas admitted from the main might flow towards the burners without passing through the working part of the meter, leaving the remaining, or one-seventh, part to perform the necessary functions of registering the amount of the whole quantity." [The manner in which this arrangement was carried into effect was simple, but effective.]

"Two openings exposed to the stream of the same volume of air or gas, however they may differ in their respective areas, will always admit quantities thereof strictly proportionate to those areas. Thus through a circular aperture of one inch in diameter will pass precisely sixty-four times as much air or gas as through a circular aperture of one-eighth of an inch in diameter; and this will hold unerringly, and under all pressures, allowing only for the additional friction the gas is exposed to in passing through the smaller opening, compared to its friction through the larger one. This theory is so well authenticated by practice that it can require no further illustration here. It is only the smaller quantity, therefore, or one-seventh part of the gas, which is necessary actually to pass through the working and registering part of the meter; and from this portion being very dry and at a high temperature, an immense advantage is derived; for as the decomposing action on the materials of the meter ceases, when the gas is hot and dry there will be little or none of that wear and tear, going on so rapidly in the ordinary water meter, from the ammonia, sulphuric acid, and galvanic action, which are the principal agents of deterioration, and which also act, though not to the same extent, upon other dry meters only exposed to the usual aqueous vapour which gas absorbs at the ordinary temperature of the atmosphere [see *ante*, p. 616].

"In hot dry gas the galvanic action ceases; the ammonia which exists in the form of gas will, when not exposed to aqueous vapour, pass off harmless; but where there is moisture present, the ammoniacal gas is instantly absorbed, and becomes a strong alkaline solution, acting on the wrought-iron parts of the meter."

After describing various metal arrangements, adopted with the view of preventing the precedingly-described actions by the six-sevenths of the gas that pass through the meter unheated, and in the condition as sent from the main, Mr. Vignolles continues—"All these requisites having been most conclusively determined *à priori*, it may be proceeded to consider the arrangements necessary to put the preceding philosophical facts to practical application in the construction of the 'Differential Dry Gas-light Meter.'

"First, the two glass cylinders, as previously described, are to be suspended in such a manner that the alcohol may be expelled from the one cylinder placed in the lowest position, and driven to occupy the other cylinder placed in a higher position. This being effected, the upper cylinder will descend and act as a pendulum, imparting motion with a power equal to the weight and height of the fluid raised. To ensure, however, the proper pendulous motion, it is necessary to attach a counterbalance to the weight of the glass cylinders and their connecting tube; and this is further required for the purpose of regulating the quantity of alcohol to be driven into the upper cylinder. The descent of this cylinder constitutes one vibration, the counter-weight giving it sufficient preponderance or momentum in its descent as to cause it to impart motion with certainty to a train of wheel-work revolving in the usual way in gas meters; and the vibration, and, consequently, the corresponding consumption of gas or light then becomes registered. * * * *

"The next considerations are—1st. How is the tube or receptacle, before mentioned, and which will be called the heater, to be placed over the lower cylinder, so that, in discharging thereupon the hot gas, it may not communicate any of its heat to the upper one? And, 2nd, how to place the upper cylinder in a medium always at the same temperature as that of the room in which the meter is to work?—it being absolutely necessary to keep the two cylinders at two greatly opposite temperatures that shall always bear the same relative degree or difference to each other.

"The first of these objects is arrived at easily by placing a tin plate between the two cylin-

ders. * * * The second necessary effect is attained by enclosing the whole meter in a thick iron case; in the interior of which, and forming part of the same casting, two semi-cylindrical projections or hoods are so placed as nearly to surround that glass cylinder which alternately becomes the upper one. The conducting power of this mass of iron is amply sufficient to carry off all the heat radiating from the case of the heater—this heater being, as before stated, enveloped in a case or clothing of the best non-conducting material; and not only so to radiate this heat, but to be always of the same temperature as the room in which the meter is placed. These hoods, therefore, constitute a very essential part of the apparatus; for if the temperature of the upper glass cylinder were to vary materially, so would that of the lower one, and, consequently, the rate of the meter would also very; but, by this very simple contrivance, the temperature of the heater, and that of the lower glass cylinder, will be always of the same relative temperature to that of the upper cylinder.

"Take an example:—Let the heater be at 150° Fah., and the room—and, therefore, the cast-iron parts of the meter—at 60°, then the gas which flows from the heater on to the lower glass cylinder will be at the same temperature—viz., at 150°; and thus the moving power, originating from the small jet, will be equal to 90°, which represents the heat imparted by the meter jet, such being a constant and uniform quantity. If the temperature of the apartment, and, consequently, that of the iron case, hoods, &c., be raised to 80°, the temperature of the heater will be increased—20° becoming 170°; the moving power being constantly 90°. It has been deemed necessary to dwell particularly on this part of the arrangement, which is absolutely essential to the correct registration of a meter, and which has been contrived in so complete and effective a manner, and by means which cannot possibly be deranged."

We have quoted the preceding extract from Mr. Vignolles' paper in the *Imperial Journal of Art*, &c., not so much on account of any practical value to which Clegg's meter has been put, but rather as an illustration of some very interesting points in physical and chemical science, and evidencing great ingenuity. Our practical readers, while feeling an interest in the details of those philosophical principles on which the invention depends, will at once perceive that numerous, and, in many cases, insuperable difficulties stand in the way of the general use of such a refined instrument.

It is impossible to convey, by written description or illustration, a proper idea of the nature of any dry gas meter; because, to be fully understood, it must be seen in action; and not only so, the variety that has been introduced into use is too great to permit of such a selection. A few practical remarks in respect to the use of any or all, may, however, be of service.

The actual amount of gas passing through a meter is registered on dials, by hands moved by a train of wheels attached to the internal and working part of the meter; and the registration is effected in tens, hundreds, and thousands of cubic feet. Throughout this country the charge is always reckoned at per 1,000 cubic feet, fractional parts, of course, being chared.

Now, the meter ought to be a satisfactory indication of gas consumption both to the supplier and the consumer; and the latter is legally bound to pay according to its indications. Owing, however, to the bad workmanship, and the imperfect principles of the early forms of meters, a general prejudice exists, to the effect that the gas companies get the best of the bargain; and, moreover, that the consumer has frequently to pay for more than he actually uses. It is true that, in water meters, an over or under-supply of water, and its temperature, together with the quantity of the vapour of water that is registered as gas, constantly tend to introduce irregularities of action for and against both the company and consumer. Hence water meters are now rarely used. But a dry meter can only act according to the amount of gas that actually passes through. In the absence of water, or any liquid, it cannot be affected either by change of level, evaporation, or any such causes. Indeed, if at first in order, the chances are that its derangements must tend in favour of, rather than adverse to, the consumer.

If all those who use gas took, or caused to be taken, the daily register of gas used, many causes of complaint at over-charge would disappear as groundless. Carelessness and wastefulness of servants in the use of gas would be checked, and a most common cause of apparent over-charge—leakage of the pipes—would be discovered, and might be prevented. An instance of the value of thus daily checking the amount of gas used, came under our notice some years ago, whilst we were connected with a well-known public institution in London, where about 1,000 cubic feet of gas were daily used. On taking the account one morning, it was discovered that 9,000 instead of 1,000 cubic feet had been consumed on the previous day. This at once indicated that a serious leakage was occurring, and every pipe in the establishment was examined, but without the cause being discovered. Eventually, however, an out-door pipe, leading to another part of the building, was looked over closely, and a small crack was discovered, through which the gas had escaped. The pipe being of iron, and long in use, had rusted, and hence the great loss just named. Had the practice of daily taking the register of the meter not been adopted, the quarter's gas account would have been at least nine times that due to the gas consumed; and, of course, as the company and the institution would have been equally aggrieved, an expensive law-suit would have resulted.

Many amusing tales have been related of private persons having to pay for gas that could not have been properly consumed, but which the meter indicated as having passed through it. In some instances the cause of error was accidentally discovered; in others it was left unravelled. But we need not enlarge on this

point, for we have shown the remedy to be very easy—that of adopting the daily registration, and, consequently, obtaining perfect control over the consumption.

Some remarks may here be made on gas-fittings, and the general management of gas; for on these two points the safe use of gas in houses, &c., depends.

All gas explosions may be traced to two or three causes. First, leakage in the fittings; secondly, escape through taps being left open; and, lastly, from the flame of a burner being accidentally blown out, the gas afterwards escaping into the apartment.

Now each and all of these causes are, in nearly every case, the direct result of carelessness, the avoidance of which would render gas explosions all but impossible. Formerly most of the gas-pipes inside a building were made of an alloy of tin, so soft that it would bend of its own weight. The pipe was soldered into that supplying the burners, by the blowpipe and soft solder. Of course the tenacity of the joint could only be slight; hence any disturbance of the position or of the staples holding the pipe was pretty certain to break away the joint; consequently leakage would take place, to the almost certain chance of causing an explosion.

A case of this kind came under our notice very recently. The pipe supplying a shop was led between the ceiling of the latter and the floor of the room above. Through an accidental shake of the shop gasalier its connection with the supply-pipe was broken, and the gas accordingly escaped into the openings between the joists of the room over-head. Gradually it reached the fire-grate in that room, and noiselessly ignited. After a short time a smell of burning was experienced, arising from under the carpet in the upper room; and, on tearing up the flooring, it was discovered that nearly all the joists, &c., were burning. Fortunately, the discovery was made early in the evening; for had the accident occurred later, no possible means could have saved the lives from death by fire of ten inmates residing in the upper part of the house.

Happily iron pipes have now become of general adoption, at least in most newly-built houses in London; and there is little doubt that, from this wise provision, house-gas explosions will become far less frequent.

Of course, whatever metallic fittings are employed, in the lapse of time they will become deteriorated; and this question can only be disposed of by leaving it in the hands of the gas-fitter. An instance of great loss, occasioned by an unknown decay of part of a gas-pipe, has already been mentioned at p. 677.

Escape through taps being left on is common, from the habit of turning gas off at the main before each separate light is extinguished. Some writers have recommended the latter plan, which, on the contrary, we cannot too strongly deprecate. In large establishments it is impossible to be always certain that every tap will be turned off after the main-cock has been closed. For example, at the institution already referred to as the place where great loss of gas occurred through an unknown fracture of the pipe, several hundred lights were in nightly use. On the top of the building, a series of rooms, occupied by a photographer, were situated; and, on one occasion, a light was left burning after the rooms were locked up for the night. As usual, at 11 P.M., the main-cock of the whole gas supply was turned off; but, owing to the gradual rise of the gas left in the pipes, sufficient of it remained to supply this one light all night; and next morning it was found burning. Fortunately this was the case; for as the gas was always turned on at the main some hours before the photographer took possession of his rooms, the whole of the upper portion of the building would have been filled with gas; and, most probably, a dangerous explosion would have resulted. Had every tap been turned off before the main-cock, such an occurrence would have been impossible.

In respect to accidents arising from the blowing out of a gas flame, and subsequent escape of gas, nothing can be remarked as preventative, except care. If a gas flame be turned down till it only presents a blue appearance, the highly conducting power of the metal abstracts so much heat as to leave barely sufficient to maintain the combustion, and the slightest puff of wind, or the ordinary draught in a room, is enough to blow out the flame. It is necessary, therefore, that sufficient gas should be allowed to burn to afford at least half an inch of white flame over the blue.

The modern telescopic form of gasalier is a frequent source of danger, owing to the evaporation of the water that keeps the two tubes that slide in each other air or gas-tight. Twice in private houses, and once in a large hotel, we had narrow escapes, with the other inmates, from this cause. In the latter instance, the landlord was a man of some scientific knowledge; and, aware of the danger, he immediately had all windows opened before the cause of the escape was investigated. But, had any of the inmates struck a light in their bedroom, the whole of the upper portion of the hotel must have been blown to pieces, and, most likely, twenty or thirty lives would have been sacrificed.

The actual cause of all gas explosions is the inflammation of the mixture of air and coal-gas, by bringing a light into contact with them. An almost constant, but most insane, practice, is that of looking for the cause of gas-escape with a light; and many lives, and much property, have been thus sacrificed.

On the least escape of gas being noticed, air should be allowed to have the freest possible access to dilute the mixture of the two gases. It must be remembered that the most explosive mixture arises from the proportion of one of coal-gas to seven or eight of air. Above or below this proportion the explosive effect diminishes; hence abundant ventilation prevents danger. The source of leakage may then be gradually traced by the smell; and, be it a leak or crack, a little putty or clay stuffed in, will at once stop the leak, and prevent all danger until

the gas-fitter can be sent for; because the pressure of the gas is too little to overcome the tenacity of either the putty, clay, or any similar viscid substance. Even a piece of rag, smeared with a paste of flour and water, will be sufficient for the temporary stoppage of a leak.

But in recommending this, we must caution against making such temporary expedients permanent. It frequently happens that a small leak is thus closed by putty or white lead, and left in that condition. After a time both of these dry, and the leak bursts out afresh, when, of course, the danger thus carelessly obviated recurs, and generally at a moment least expected.

One part of London coal-gas mixed with even 500 parts of air, gives a sensible smell; and, of course, as the proportion increases, the smell also increases. This is one advantage in coal-gas, for it acts as a warning before danger can occur.

Although coal-gas has only about half of the specific gravity of air, it does not follow that it will rise to the top of the room in which it escapes. This we have already noticed, and, at the same time, explained, that, by virtue of the diffusive power of gases, coal-gas and air have a tendency to mix, despite the difference of their specific gravities. Of course, in attempting to remove an explosive mixture in a room, the top and bottom of the windows should be opened, so that an in and out-current may be established. But we again insist on this peculiar diffusive power of gases, for the purpose of pointing out, that any supposed safety, arising from the levity of coal-gas causing it to fly to the top of the room, is, practically, a dangerous delusion.

This leads next to the consideration of the best means of ventilation in places where gas is used as an illuminating agent.

Many schemes have been proposed for this purpose, and for ventilation generally. Some have been characterised by great scientific knowledge, with but little practical value; whilst, on the other hand, some plans, extremely simple in themselves, have proved very advantageous in practice, and have, consequently, been largely adopted.

All methods of ventilation, however, depend on very simple principles; such, indeed, as are of constant adaptation in nature, and hence necessarily useful to man.

The essential point in ventilation is that of availing ourselves of what is called the law of *convection*. This means that gaseous bodies, such as the atmospheric air, &c., and, indeed, all fluids, become specifically lighter on being heated, and have a tendency, in consequence, to ascend in any vessel or confined space.

This principle, or law of convection, is amply illustrated by a very simple experiment. A tall, wide beaker-glass may be first filled with cold water; and then, by means of a funnel with a long stem, reaching to the lower part of the vessel, a strong solution of sulphate of copper in water may be passed in. If this be carefully done, the copper solution will form a stratum that will occupy the lower part of the vessel; and from its greater specific gravity, it will remain there quite distinct from the rest of the fluid or uncoloured water.

A red-hot iron may next be dipped an inch or two deep into the water at the top of the beaker; but so trifling is the conducting power of the water *downwards*, that the temperature of the whole mass of the fluid will be quite unaffected. If, however, the bottom of the beaker be immersed in a basin of hot water carefully, so as not to disturb the blue copper solution at its bottom by shaking, shortly after the introduction of the beaker into the hot fluid, it will be noticed that the blue solution becomes in motion. It will gradually arise in upward currents in the vessel, indicating that the particles of the fluid have been set in motion by the heat; that they consequently ascend; and that, as may be proved by immersing a thermometer, the temperature of the entire mass of the liquid becomes raised.

This simple experiment illustrates at once the nature of what is called *convection*, which is really, after all, only, in common phraseology, the conveyance of heat upwards, by means of the particles of matter, fluid or gaseous, in motion. It is on this principle, then, that nearly every scheme of successful ventilation, either for ordinary purposes, or in the case of gas illumination, depends.

Whenever a gas or other heat-light is lit in a room, this principle of convection is called into action; and, in the case of gas, it is largely in operation, because of the amount of heat produced, which, although less in respect to its lighting power as compared with candles (see *ante*, p. 567), *cæteris paribus*, is always practicably far greater than that of any ordinary illuminating agent.

The gas-flame, then, causes an upward current in a hall, room, or any other place; but to prevent any repetition of such names, we shall use the term "apartment," as designative of any enclosed place, large or small. This upward current may consequently be made most effective in carrying off all the products of gas-combustion; and also be equally applied for the purposes of general ventilation. Indeed, by proper management, gas is the best means of ventilating an apartment.

But although convection is essential as a principle of ventilation, its practical details involve additional considerations. Thus, if gas be burnt in an apartment closed at top and bottom, two results must occur. In the first place, there will be no means of exit for the hot air, and none of ingress for cold or fresh air. Therefore, in such an apartment, after burning gas for any lengthened period, the air will become close, hot, unhealthy, and even injurious, perhaps dangerous. The reason of this will become at once obvious on perusal of the account that has been given of the vitiating power of all artificial illuminating agents, at p. 567, *ante*.

As, however, we have seen that hot air is specifically lighter than cold air, and, further, that hot air always ascends, it becomes evident

that by making an opening at the top of an apartment, we may get rid of heated and impure air. But whilst such a provision is made for emitting or driving off the products of combustion, &c., it is equally necessary that we should grant a supply of fresh air to replace that which thus passes off at the top of the apartment.

Nearly every scheme of ventilation fails because, whilst abundant provision is frequently made for the escape of the hot air, but little provision is made for the ingress of an equivalent portion of cold, or fresh air. No sensible man would expect a balance at his banker's to remain always the same if he constantly drew cheques without paying any money in; but, in practice, we regret to say that, in the large majority of instances, this precisely illustrates the methods of so-called ventilation, as practically carried out in this kingdom in nearly all our churches, chapels, theatres, music-halls, &c. Hence, even in day-time, they become offensively close, and, at night, are insufferable. Indeed, the greater number of our judicial chambers are frequently so ill ventilated, that even the patience of those sober-minded individuals, the judges, becomes ruffled. Amongst such intelligent individuals we might expect the force of authority and intelligence to effect some weight; but, alas ! it has been our doom to sit for two hours together in a room holding fifty of the most celebrated scientific men; the apartment lit with gas, and utterly unprovided with the least means of ventilation except by opening two or three window-tops out of sheer desperation. And if the children of Wisdom so treat her, what may we expect of those who know her not, or despise her ?

The simplest mode of effective, but not always convenient ventilation, is that of allowing the ingress of cold fresh air at the bottom or sides of a room. In a private apartment, a few holes bored with an auger at the bottom of the door, whilst an ornamental piece in the ceiling, covering an aperture that leads from the top of the room into the outer air, is an efficient and, generally, complete means of ventilation. Some years ago this principle and practice were adopted to the fullest possible extent in ventilating the houses of parliament. The floor was bored with an infinity of holes, to supply fresh air; whilst the hot, foul air was got rid of in the usual manner at the top. Our legislators became by no means pleased with this purely scientific mode of ventilation, and, consequently, it was abolished.

The sun-lights, already described at p. 621, *ante*, afford an excellent means of carrying out complete ventilation in the shop, drawing-room, or the largest hall. Fixed in the ceiling of such apartments, they, of course, draw up a constant current of air, which becoming heated, is allowed to pass off by the roof into the atmosphere; and if, by any proper contrivance, a sufficient admission of fresh air at the lower part of the apartment is permitted, nothing can be devised more effective, or easy of execution.

Of course, the mode of admitting air to any apartment or place, large or small, must be regulated by its position, size, and other conditions. It is, therefore, evidently impossible to give any directions or advice that can be universally applicable in detail. We must rest content with the simple enunciation of the principles already afforded.

Apart from the unhealthiness and inconvenience of burning gas in a confined place, we have already pointed out how the products of its combustion, if confined, act injuriously on property, in regard to books, furniture, &c. (see *ante*, p. 609). Take, for example, the windows of drapers' and other shops, lit internally. In winter-time they are generally covered with dew, or condensed steam, which quite prevents a sight, from the street, of any of the wares temptingly arranged to attract customers. Every grain of hydrogen consumed deposits on the window nine grains of water. Added to this are the sulphurous and sulphuric acids, which, as before repeatedly mentioned, seriously affect both the colour and texture of all textile fabrics—in the course of time destroying both : hence, of late years it has become a common practice to light such windows externally with lights hung in front of the window in the street ; and this practice, whilst removing all objection as to the production of chemicals internally from the combustion of the gas, has the additional advantage of reflecting abundance of light on the goods, whilst the eyes of the lookers-on are protected from its glare.

Faraday was, we believe, the first to examine into and propose a remedy for the evil that results from the combustion of gas in unventilated rooms. It has already been stated that, owing to the destruction of the books of the Athenæum Club (of which, by the way, he was the honorary secretary at its commencement), he was desired by the directors to investigate the cause, and suggest means for the cure of the evil. He tried several methods, and, at last, decided on a plan that has since been known by his name. A general detail of the principles on which he proceeded, and the results he obtained, will be therefore given; because, although his method has numerous objections, that have greatly limited its adoption, still he laid the foundation of principles, the application of which has resulted in many of the improvements now offered for, or adopted in, general use. An ordinary Argand gas lamp, alight for four hours, will, by the combustion of the hydrogen with the oxygen of the air, afford not less than two pints and a-half of water ; and for every cubic foot of good gas burnt, about a cubic foot of carbonic acid gas is given off by the union of the carbon of the hydrocarbon with the atmospheric oxygen through combustion. We have already noticed that the presence of this gas, even in trifling excess, in the air, is injurious ; but if largely present, it becomes dangerous and fatal. Added to this is the sulphuric acid just spoken of as so injurious to furniture, &c.

Faraday contrived a method of burning the gas in a room, large or small, by which the entire products of combustion are conveyed away

direct from the burner, and without even entering the room at all. This plan was, therefore, complete in a hygienic point of view; for, of course, whilst no gas products could enter the apartment at the same time, the ventilation of the latter by the supply of air to the burners, essential for proper combustion, was simultaneously carried on.

The plan was exceedingly simple. Thus an ordinary Argand burner, surrounded by its chimney, was placed inside another and larger glass, quite closed at the top by means of a plate of mica. The products of combustion, escaping from the internal chimney, impinged on, and were diverted by the mica plate, passing off on the outside of the gas chimney, and within that of the external one, into a tube connected by an external shaft with the open air. The supply of air to the burner was the same as by the usual method. The chief objections to this form of lamp are the necessity of special provision for fixing it and the tube withdrawing the products of combustion, and also the frequent breakage of the glasses. Of course a strong current is required to maintain the withdrawal of the heated air; hence it is most suited for large establishments, as in the club-house, for which it was first designed. It was subsequently used in some of the royal palaces, and many public establishments; but it has not been employed in recent years. Faraday recommended, very justly, its use, on the grounds that the additional apparatus necessary for the purpose was not objectionable in architectural appearance; that the ventilation of the lamp was perfect; the light was increased from 10 to 20 per cent.; the heat given out in the room was lessened; and additional safety from accidents was attained, as, in the event of any leakage from the pipes, or from a gas-cock being inadvertently left open, the gas, instead of escaping into the apartment, would be carried off.

It is evident that, at all times, gas may be safely and properly used, whether as regards health, furniture, &c., if proper ventilation is carried out, and due care taken for its careful management. We are, however, so used to coal-gas, as a matter of daily-life use, that we are apt to neglect the commonest precautions in respect to its employment. Persons will calmly engage in their domestic or business avocations with an escape of gas into the house or shop that may become highly dangerous; and yet the very same individuals would be horrified at the idea of having a pound of gunpowder on their premises, although the explosion of the latter would produce far less harmful results than one of gas. But familiarity with danger, as with humanity, breeds contempt, and hence the gross carelessness evinced in the use of gas. It is only the burnt child that dreads the fire; and, in a similar way, only those who have witnessed the effects of an explosion of gas, receive sufficient warning as to the necessity of the strictest care in dealing with it.

Most of our readers will be familiar with accounts of gas explosions that have occurred in recent years, and can judge of them from descriptions in public prints. Many form an ideal estimate of the serious effects they produce; but none can form any truthful idea but those who have either seen the act of explosion, and its immediate consequences, or carefully inspected the results. A short time ago we happened to be witness of one of those occurrences. A burner had been left but partially alight, and, it is supposed, through a draught in the room in which it was burning, the flame became extinguished. The person in charge of the house had gone, for an hour, out of the apartment, and returned to it with a candle alight. Instantly an explosion took place; all the front windows were blown out; every vestige of paper was instantaneously burnt off the walls; whilst all the private windows of the opposite houses, sixty feet off, had the panes of glass broken. Although at the time a hundred feet distant, the concussion of the explosion drove us off the pavement. A fearful explosion, that occurred in 1848, in Albany-street, Regent's Park, will be within the memory of many of our readers. It resulted from a crack in the meter, by which the air, in a comparatively small room of only 1,600 cubic feet capacity, became explosive. The result was one of terrific violence: the pavement in front of the house was torn up for a considerable length; a roof was blown to a distance of 200 to 300 yards from an adjacent house; upwards of one hundred houses were more or less injured; and a total damage of at least £20,000 occasioned—all from the explosion of a few grains, in weight, of coal-gas. Still more recently a fearful explosion of gas took place in Tottenham-court-road. By this the houses in four adjacent streets were completely wrecked, the roadway for over a mile torn up, causing great loss of property, but fortunately of only one life.

We have thus endeavoured to trace the history, manufacture, distribution, consumption, &c., of coal and other gases used for illuminating purposes, and procured by the dry distillation of substances containing hydrocarbons; and must now conclude our remarks on this interesting and extensive subject by the notice of two forms of light, indirectly connected with coal-gas by the relationship which hydrogen has in the case of one of them, but directly connected with the subject of artificial light generally: we refer to the *lime* and *electric* lights. We shall dismiss all notice of the light produced by burning magnesium, with the remark that, although it is exceedingly intense, pure, and actinic, no practical success has yet arisen in its application.

The lime, oxy-hydrogen, or Drummond light, is produced by the combustion of the gases oxygen and hydrogen; the flame thus, although not luminous, producing a most intense white light when allowed to impinge on a piece of lime, magnesia, or zirconia; the first, however, being always used, as it can be easily cut or turned into cylinders, which is the most suitable form for its employment.

According to the original method of obtaining

this light, oxygen, afforded by heating the black oxide of manganese, and hydrogen by the decomposition of water in the manner already explained, were mixed together in a bladder. The mixed gases were then passed through a tube filled with circles of wire gauze tightly packed, or through a tube, also tightly packed with thin rods or wires; the object of both plans being to prevent the retrogression of the flame through the jet to the bladder, or other receptacle of the gases—a result which would be accompanied with a violent explosion. Eventually, however, it was found far safer to keep the gases in two separate holders, and only to allow them to mix as they issue from the jet. A pipe of small bore, in the best form of the jet, is inserted in one of a little larger bore. Between these pipes the hydrogen finds its way from the holder to the jet, where it is ignited. The small internal tube being attached to a holder filled with oxygen, this gas is then turned on. The yellowish-red flame of the hydrogen is thus lost, and a blue one, of intense heating power, is afforded, the length, &c., of which is kept uniform by regulating the supply of either or both gases by means of stopcocks.

A constant jet of flame may be thus kept up so long as the supply of the two gases is maintained. It is cast on to a cylinder of hard lime, about an inch and a-half high, and three-quarters of an inch in diameter, and instantly, on touching it, a dazzling bright light is afforded. The cylinder is usually kept vertical; and as portions of the lime are volatilised by the intense heat, the cylinder is kept rotating by means of clock-work, so that fresh surfaces shall be continually exposed to the action of the flame.

The amount of light thus produced is exceedingly great, and its penetrative power is equally so. By means of a parabolic reflector, this light has been directed to a station sixty or seventy miles from its source, and was distinctly visible.

Owing to its brilliancy and penetrative power, it was first proposed and used by Lieutenant Drummond, as a means of night-signals in the trigonometrical survey of Ireland; his early experiments being reported in the *Transactions of the Royal Society*, in 1830. At that time the inventor had sanguine hopes of converting it into a means of lighthouse illumination; and extensive experiments were undertaken to adapt it for that purpose. Like, however, many other excellent scientific inventions, admirable in the laboratory and lecture-room, it was found inconvenient and practically impossible; and for many years its uses were mostly confined to the illumination of dissolving views at some public institutions, varied with an occasional outburst of some possible application, that, however, up to the present time, has never been made. The last attempt that we witnessed of this kind was that of lighting up Westminster Bridge. The effect was most beautiful; but the experiment terminated, after a few days, in an accident that, we were informed, proved fatal. Indeed, to deal with such gases as oxygen and hydrogen safely, requires long practice, and some scientific knowledge; and even with these requirements we have witnessed accidents, that but for collateral precautions, would have resulted in very serious results, where but small holders or bags of the gases, that had accidentally mixed, exploded through retrogression of the flame, or other cause.

Another objection is one which has until recently been equally applicable to the electric light. It is the want of diffusive power in either of them, and the consequent deep black shadow both cast when impeded in their progress by any solid opaque body. This proves highly detrimental to their use at night for illuminating purposes, except in lighthouses, where, of course, no shadow is produced, and a brilliant, intense, penetrative ray, direct in one line, alone is required. We have tried a vast variety of experiments to induce, by secondary means, a greater diffusive power, as by sending the rays of each through white smoke, &c.; but have entirely failed.

Of course, in attempting to apply the lime-light to lighthouse illumination, many objections arise. Usually such places are at some distance from any town or port whence the materials can be obtained or shipped for use. Near gas-works, coal-gas may be substituted for pure hydrogen, as it is just as effective, only requiring more oxygen, but still doing away with the necessity of decomposing water. Yet the manufacture of oxygen, although apparently simple, requires many precautions; is attended by considerable expense; requires the erection of gas-holders, &c. To obviate these objections, it was at one time proposed to substitute the decomposing action of the voltaic battery on water, and thus cause the simultaneous evolution of the gases in exactly such proportions as are required for the purposes of the lime-light. When this was first proposed, we fitted up an apparatus, of the best construction, for the purpose; but found that, whilst very interesting as a lecture-room experiment, or as a matter of surprise in the illumination of a room for an evening party, the method is attended with far too much trouble, expense, and difficulty, to make the proposition of the least practical value.

We next turn to a short description of the electric light, that, as already mentioned, has been proposed and is now largely adopted as an illuminating agent for lighthouse and other purposes requiring intense penetrating power. This light, whilst primarily derivable from current electricity, is, so far as the production of the latter is concerned, dependent both on chemical and magnetic induction.

The voltaic battery is an arrangement by means of which the latent electricity of water is set free. It essentially consists (at least, so far as any usual form of cell or battery is concerned) of two metals, and one or more liquids. In the old forms, a plate of copper was placed, facing one of zinc, in a vessel containing water, acidulated by either sulphuric or nitric acid—sometimes both—the zinc of one vessel being connected with the copper of the next; and so on through a series of any number. The extreme zinc and copper of the series had each a wire

attached; and at the other extremity of these wires the electrical effects are manifested. In such an arrangement, as soon as the two terminal wires are caused to touch each other, a current of electricity is generated, that passes through the whole series. If these wires be first brought in contact and then separated, a bright spark passes; and if the battery be sufficiently powerful, this spark is continuous, becoming a bright arc of light, the length and brilliancy of which depend on the energy of the battery. Its colour is influenced by the nature of the wires, all the metals giving coloured flames, whilst that of charcoal is pure white.

But such a form of battery is far too inconstant in its action to be of the least use as a light-producing agent. Even within a minute or two after it is excited, and the current is produced, its power degenerates, unless the battery be of great extent—as that Sir Humphrey Davy employed, containing about 2,000 pairs of plates, which was constructed on the plan just described.

The first step for bringing the voltaic battery into possible use as a light agent, was the invention of the constant battery by Professor Daniell. In this zinc and copper are used, as above; but in place of acid and water alone, two solutions, separated by a porous diaphragm, are used—near the zinc, one of dilute sulphuric acid; that next the copper is composed of a saturated solution of sulphate of copper, to which an eighth portion of sulphuric acid has been added. Crystals of sulphate of copper are suspended in the solution to keep up its strength.

Grove's battery, or its modifications, is really the only one that can be practically employed; for, whilst having considerable constancy, it has far greater power than either of the preceding. In it platina—next which is strong nitric acid, separated by a porous pot from water, to which a sixth part of sulphuric acid is added—and zinc are the metals used. Owing to the energetic action of the battery, a force may be generated by one occupying a space two feet square and six inches high, that will afford a light equal to 2,000 sperm candles: in other words, speaking in comparison with gas, equivalent to 100 jets of twenty-candle gas, all burning at once; with a light, however, greatly superior in whiteness.

When the terminal wires of such a battery are tipped with a piece each of charcoal, or hard gas carbon as frequently applied to this purpose, and these pieces be touched together and withdrawn, a most brilliant arc of flame is produced, resembling that represented at page lxxviii. in the Introduction. An arc of the size there illustrated, although so small, would afford a light quite equal to that just described—that is, of 2,000 sperm candles.

In the Introduction the history of the electric light is fully detailed at page lxx., *et seq.* One of the best machines now used for its production is illustrated, viz., Lontin's. In a a subsequent Chapter the whole subject will be fully entered into, and all the modern machines employed in the production of the electric light will be described and illustrated.

FATS, OILS, WAX, PARAFFIN, ETC., AS SOURCES OF ARTIFICIAL LIGHT.

It has been already stated that oil-lamps seem to have been about the earliest sources of artificial illumination. Our museums are well stocked with a great variety of lamps, of Roman, Egyptian, and other kinds, some of which have been illustrated in the Introduction. The fact that the ancients were quite unacquainted with any method of extracting stearine from fats, and of so obtaining a material that would stand the heat of their climate in summer-time, reduces us to the conclusion, that wax and vegetable oils could have been the only available sources of light, at all events, in Egypt, Asia Minor, Arabia, and India.

The applications of chemistry in various processes connected with oil-refining and candle-making, during the last thirty or forty years, have been very extensive; having, indeed, revolutionised the trade. Many of our readers will remember that, in their younger days, the only good form of candle that could be obtained was that made from wax; those of tallow, as dips and moulds, requiring to be snuffed continually—spreading sparks and grease around them, and guttering if placed in the least draught. The materials for the manufacture of candles were confined entirely to animal fats and beeswax.

At the present day, a great variety of candles is made from stearine of animal fat, and that obtained, as cocine and palmitine, from cocoa-nut and various species of palms, affording "butters," or vegetable fats; from sperm, obtained from a species of whale; and last—and perhaps the best of all—paraffin, distilled from coal.

In regard to oil, at the period just referred to, the house-lamp required the best sperm oil, all other inferior kinds being devoted to kitchen and out-door use. Now our sources of lamp oils are extremely numerous, both in respect to the animal and vegetable kingdoms, as we shall see when we enumerate and describe the chief of them; and the older kinds of oil, formerly thick and bad for burning, are far better refined for such purposes. Lastly, in respect to oils, we need but mention paraffin and petroleum, to show how much chemistry has done for this department of artificial illumination.

In regard to wax, our sources of this material were formerly confined to that secreted by the bee. A great quantity, however, is now obtained direct from the plant, and largely imported into this country from Japan, and other Asiatic countries, West Indies, &c.; opening out, not only a trade of export from such places, but also adding to our own exports by the demand created for home manufactures.

Before entering into a description of the properties of each kind of fat, oil, wax, &c., used for lighting purposes, attention must first be drawn to some general facts and principles applicable to them all; and to certain qualities, the

possession of which is a condition of their utility for the purposes to which they are to be applied.

Whilst complete fluidity, even at low temperatures, is essential to oils for use in lamps, all materials intended to make candles, are of value in proportion as they resist liquefaction; that is, *cæteris paribus*, the higher the melting temperature, the fitter is the material for candle-making.

Now, all oils and fats consist of, at least (commercially speaking, only for the present), two parts—the fluid or true oil, and the solid or stearine. By this term, only the solid part of tallow from the ox or sheep is usually intended; but, for the sake of simplicity, we shall include cocine, palmitine, &c.

It will therefore be evident, that not only may every animal and vegetable fat, or oil, be employed in a twofold manner—affording, as they do, two products—but, beyond this, the separation of the two is necessary for the individual purposes to which each is applied.

For example, taking common tallow, it is well known that it melts at a comparatively low temperature. In summer-time, even in this climate, dip candles soften, and break almost from their own weight. The tallow, in this condition, is formed of a combination of the fluid oil, or oleine, and the solid matter, or stearine; and, on an average, it melts at from 95° to 105°. If, however, by processes to be subsequently described in detail, these two constituents are separated, we then obtain an oil and a solid; the latter melting only at a much higher temperature, averaging, in ordinary stearine candles, from 130° to 135°. This temperature is, of course, much higher than that at which the atmosphere can rise in any part of the world; hence such candles may be stored and kept in hot climates without danger of loss.

On the other hand, oils contain more fluid oil and less stearine than tallow; hence, for the most part, they are fluid at ordinary temperatures in this country. Palm, cocoa-nut, and many other oils, more fluid in the hot climates in which they are produced, are of the consistence of butter as used with us, because the decrease of temperature they undergo, causes the separation of the stearine in the same way as may be observed with olive oil, which, whilst fluid in summer, in England, becomes in winter-time at a low temperature, of the consistence of butter, owing to the separation of its stearine. This circumstance, some thirty or forty years ago, was a source of constant annoyance in using oil-lamps; for, in winter-time, it frequently happened that the oil in the reservoir was solid from this cause, and required melting before the lamp could be used.

It follows that the temperature of liquefaction is, therefore, of great importance in the choice of oils, fats, &c., for lamp or candle purposes. Indeed, it lays at the foundation of the purifying of oil, and the production of material for candle-making. The following table is an approximate statement of the melting-point of various fats, oils, &c., used for the purposes just named.

Fat or Oil.	Temperature of Liquefaction or Solidification.
Tallow	98° to 104°
Palm oil	80° ,, 96°
Cocoa-nut oil	68° ,, 70°
Ghea oil, or fat	97°
Ilpa do. do.	70° to 80°
Tallow-tree fats	90°
Piney tallow	98°
Cocum butter	95°
Palmitine	117°
Cocine	110°
Margarine	117°
Stearine	135° to 145°
Cetine	115° ,, 120°
Sperm or Spermaceti	115° ,, 160°

Four of the last six in this table consist of the solid matter extracted, respectively, from palm oil; cocoa-nut oil; margarine and stearine from tallow; and the two last are obtained from various species of the whale, dolphin, and allied tribes. To make the list complete, we add that good beeswax melts, unbleached, at 145°; and bleached, at 148° to 150°; whilst its two products, analogous to palmitine, &c., and that are cerine and myricine, melt at from 162° to 170° for cerine, and about 147° for myricine.

Another important point in relation to the temperature of liquefaction, is that of the economy of use of such fats when converted into candles. It will be convenient here to remind our readers of what has already been stated at p. 566, *ante*, in respect to the candle value of gas. It was there observed that a sperm candle, burning at the rate of 120 grains per hour, is used to test the photometric value of gas, as supplied by the companies. As a rule, it is found that the lower the temperature of liquefaction, the more rapid the combustion, and, therefore, use of the material, and the less the light. For example, a mould candle, of six to the pound, consumes about 145 grains in the same time that a similarly sized sperm candle would use but 120; and yet only affords one half the light. A dip candle, of similar size, would consume from 150 to 180 grains, giving not more than a third of the light of the sperm. Composite candles consume about 150 grains per hour, with about the same amount of light afforded as that from sperm; whilst a yellow palm candle consumes about 160 grains, giving a like amount of light. Hence, as before stated, the higher the temperature of liquefaction of the material, the greater its economy, putting the question of original cost, of course, quite out of consideration.

These facts strikingly show how much the laws developed by science affect all matters of our existence. Formerly, they were either not known, or were ignored. At the present day, their consideration, in relation to the subject now before us, not only has become a question of great domestic importance, but, owing to the demand created for new material (previously all but valueless), has enormously expanded the home and foreign trade of this and other countries; and, still better, has greatly dimi-

nished the capture of, and trade in, slaves on the western coast of Africa.

The next question of importance, apart from those of a chemical character (for we are here dealing, at present, with only such as are of a physical nature), is that of specific gravity. All oils, &c., that can be used for illuminating purposes, have a gravity less than that of water; and, in that relation, they vary from about 885 to 965; water = 1,000. The following table exhibits the specific gravity of some of the chief oils, &c., in ordinary use; and, in it, water is considered as 1,000.

Specific Gravity of some Oils and Fats.

Oil, &c.	Specific Gravity.
Sperm	885
Tallow	900
Colza	914
Ground-nut	915
Sessamum, or Gingilie	916
Almond	917
Train (whale)	923
Fish	924
Cameline	925
Sunflower	926
Hemp-seed	926
Cod	928
Seal	929
Linseed	930 to 960

It is impossible to trace, from the preceding, any individual connection of specific gravity with illuminating power; because, in each of the oils or fats, the oleine and stearine, or solid and fluid matter, have been included; that is, the specific gravity of each has been taken with the material in its natural state. It is by no means unlikely, however, that if these various oils had the oleine and stearine separated, and the specific gravity of them with that of the natural one were compared, we should find some relation to exist between them, the temperature of liquefaction, and the amount of illuminating power afforded, whether the latter be tested by the lamp or candle.

At a little over 600°, all the preceding oils and fats become gradually converted into vapour, and may be distilled over if out of contact with air. And here we may point out the distinction that subsists between volatile and fixed oils. Volatile oils are those that may be readily volatilised at moderate temperatures. Thus, if a piece of paper were wetted with oil of roses, lavender, rosemary, and others used in perfumery, and held for a moment over the flame of a candle, they will evaporate, and leave the paper quite clean. But if any of the oils or fats mentioned in the preceding tables be similarly dealt with, they leave a permanent stain on the paper that cannot be removed by a heat less than that sufficient to cause the burning of them and the paper, when both become decomposed. By this means perfumers distinguish otto of roses in its pure and adulterated state. As it cools it deposits needle-like crystals, much resembling spermaceti, which is, consequently, a frequent adulteration of the genuine otto. But the fraud may be readily discovered by putting a drop of the oil on paper, and holding it over a candle flame. If pure, the otto will entirely evaporate, leaving the paper unstained; but should spermaceti be present, it will communicate a greasy stain to the paper, because, like all the fats, &c., now to be dealt with, and previously named, it is *fixed* in its character.

Above a temperature of 600°, all fixed oils become chemically decomposed; that is, they are resolved into hydrocarbons in a precisely similar manner to coal; and the hydrocarbons thus afforded are inflammable in contact with oxygen as in the atmosphere. Their constitution varies; but for all purposes to which we have to direct attention, we may consider them as composed of variable proportions of hydrogen and carbon, which, during combustion, afford water and carbonic acid, owing to the oxidation of these elements by union with atmospheric oxygen. Practically, therefore, the combustion of gas, oils, and candles may be considered as identical, whether as regards cause or effect; excepting, however, that, unlike gas, fatty matters afford no compounds of sulphur, or other impurity common to gas.

We have already pointed out, in fact, that the candle and oil-lamp are really "gas-houses" on the small scale, the entire operation of converting the material into illuminating hydrocarbons being carried on at the junction of the wick and flame. The material is raised, by capillary attraction (see *ante*, p. 568), to the black portion of the burning wick, which acts on it, converting it into luminous gas, just as the retort of the ordinary gas-house effects similar changes on coal. But here the parallel fails; for, no intermediate steps between production and combustion are required in the case of the candle and lamp, as are needful in respect to gas.

Whilst speaking of the products of oil-combustion at a high temperature, we may observe, that several, if not all, oils possess the property of absorbing atmospheric oxygen, and of thus becoming permanently changed. Indeed, it is on this principle that the drying or boiled oils of the painter and varnish-maker are manufactured. They are boiled for some time with an oxide of lead (litharge), which they gradually decompose, seizing its oxygen, and becoming, in part or wholly, converted into a gum or resinous-like matter; at last entirely drying up, without the least sign of oil, on exposure to the atmosphere. This may be readily observed in the ordinary process of house-painting. The pigments are mixed, in various proportions, with boiled linseed oil and turpentine; and, after being laid on the work, the paint speedily dries into a solid. This property, in respect to linseed oil, has recently been utilised to produce a kind of floorcloth, that possesses many advantages over other kinds.

Two serious results, however, arise from this oxidising process. It will be familiar to all our readers that cases of spontaneous combustion frequently occur; and when such is really the case, it is always traceable to the gradual oxidation of oils, in contact, generally, with some

vegetable fibre, as cotton, linen, hemp, jute, paper, &c. Frequently, bags of cotton waste, containing what are called "strips" and "flys," into which oil has fallen, heat rapidly, and, in some cases, catch fire from this cause. Many of the largest fires that have taken place in London and Liverpool, at the wharfs, warehouses, and docks, have been due entirely to spontaneous combustion, produced by such means. This gradual process of oxidation, and its consequences, may easily be examined by smearing a piece of cotton wool or rag with *unboiled* linseed oil, and placing it between a few folds of paper, with a weight to keep all pressed together. In summer-time, the rag, paper, &c., will often catch fire, owing to the oxidation of the oil employed in the experiment. Hence the great necessity that exists of care not to throw into a heap cotton or other rags containing oil, lest ignition may take place.

The second result bearing on our subject, as due from the oxidation of oil, is that of the filling up of the pores of the wick of lamps, when the common oils are used. Some five-and-twenty or thirty years ago, when oil-lamps were so much in vogue, and when the nature of oils was but little understood, comparatively speaking, any attempt to economise oil by using the lower sorts in place of sperm oil, was always followed by the annoyance of the clogging of the wick. Now this arose partly from the stearine and some impurities present, but chiefly from the oxidation of the oil by absorption of atmospheric oxygen. Of course, the wick soon became useless, and had to be renewed; the expense of which, together with the loss of oil in cleaning the lamp, inconvenience, &c., dissipated all economy in substituting a low for the best kind of oils. We may here notice, that paraffin oil is free from either of the objectionable consequences just pointed out; as, not being at all disposed to absorb oxygen, it can be advantageously used for burning, and safely as a lubricant for machinery, especially such as may be employed in the manufacture of textile substances, as cotton, hemp, &c.

We must next turn to the effect of chemical action on oils, &c.—a matter of the highest importance in every branch of our subject; for on that depends the production of all the varieties of candles, and most of the improvements and purification of oil at the present day.

Pure fixed oils are characterised by entire insolubility in water, whilst volatile oils are partly soluble in that fluid; hence such products as elder, rose, orange-flower, and other waters, in which a minute portion of the oil is present. Such must not be confounded with the spirituous solutions of the essential oils, as lavender water, Eau de Cologne, &c., which are solutions of those oils in spirits of wine. All alkaline substances, such as potash, soda, ammonia, lime and other alkaline earths, have the power of apparently causing the solution of the oil; but, really, a chemical change takes place, and solution is merely the result of this.

If soda, for example, be heated with water and any of the fixed oils or fats, the well-known cleansing material, soap, is formed. The soda unites with the acids, that constitutes the fat, and form a definite compound of acid and base, precisely in the same way that sulphuric acid would act if added to a solution of soda, in which case a sulphate of soda would be produced. Now, on the addition of an alkali to fats, &c., their acids—the oleic, stearic, margaric, palmitic, cocinic, bassic, &c., &c.—unite with it, and form genuine and real salts, called oleates, stearates, margarates, &c. Soap is, therefore, in reality as much a chemical compound, or salt, as are Epsom salts, sulphate of soda, nitre, or any other.

If such a salt be formed—that is, if an oil or fat be heated with water, and an alkali and more water be added to make a dilute solution—the salt may be readily decomposed by the sulphuric and many other acids which, uniting with the alkali, will set the fatty acids free. Thus, if ordinary soap be dissolved in some hot water, and a little sulphuric acid be added, the soap is decomposed, its alkali attaches itself to the sulphuric acid, and its fatty acids, the oleic, stearic, &c., are left in the fluid, respectively, as liquids and solids. In this way may stearine, margarine, palmitine, cocine, &c., be eliminated from tallow, palm, and cocoa-nut oils. We are indebted to Chévreul, the eminent French chemist, for this discovery—one that has entirely altered and improved the treatment of both fats and oils for lamp and candle purposes.

But the same result, the elimination of oleine, stearine, &c., from the substance containing them, we have already shown may be effected by cold; for even the most fluid oils deposit their stearine as their temperature is lowered; and, by pressing the pasty mass between folds of blotting-paper, the oleine will be absorbed, being the most fluid part, whilst the stearine is left as a solid white mass, that will retain its solidity permanently when thus freed from the oleine. By great pressure the same result may also be obtained. Thus, if palm or cocoa-nut oil, and other vegetable fats, or tallow be melted, allowed to cool very slowly, and kept in constant agitation whilst so doing, they will assume a kind of paste-like form. At this point they are placed in bags made of linen or horse-hair, to allow of the oleine passing off in the subsequent process, which is that of submitting the mass to high pressure, as by the hydraulic process. By this most of the oleine is driven off as a yellowish liquid, whilst the solid part is retained. If melting and pressure be thus repeated, the stearine, palmitine, &c., may be obtained as a white ivory-like mass, greatly differing in every quality from the materials that thus afford them. It will thus be seen that the essential value of either the chemical or mechanical processes, is that of isolating the constituents of the fats and oils.

So far for the action of the alkalies and alkaline earths or fats. We may next glance at the action of acids on them, which has been turned to advantageous account as a test of the character, value, and adulteration often practised.

If strong sulphuric acid be added to any fixed oil, it speedily decomposes it by abstracting all its hydrogen and oxygen as water, for which it has great affinity, and setting the carbon free as a black mass. This may readily be seen by pouring some of the strong acid into a Florence flask containing a little salad oil, when the precedingly described effects will be noticed, attended with the production of heat. Precisely the same result is afforded on pouring concentrated sulphuric acid into a little syrup, when the latter will boil up with great heat, and the deposition or separation of the carbon of the sugar will take place.

By modifying the action of this acid, the nitric, chromic, &c., a means is afforded of discriminating between each kind of oil; and so accurate are the indications, that even mixtures of the oils produce results intermediate between those shown individually. The following is a brief outline of the method:—

About eight or ten drops of the oil are put into a white plate, and into the centre of the oil a single drop of the acid is poured. The acid may either be left to act radially from the centre, or stirred into the oil; the latter method hastening the effect. Another plan, which whilst it lessens the rapidity of the action, gives more time for observation, is to add about one-third in bulk of water to the concentrated acid; but this plan also modifies the results.

Sulphuric acid gives the following indications.

With whale or train oil, a reddish brown colour, with violet edges, is produced, if the acid be dropped into the centre of the oil; if stirred into it the whole mass becomes of a tawney red, or dark violet-brown.

Seal oil first affords a yellow colour, passing to an orange, and to a dark brown with purple spots interspersed. On stirring the mixture, at first it affords yellow, and then orange-brown.

Liver oils of all kinds change from their colour to a violet, with carmine edges, changing to orange, and subsequently to dark brown. By stirring, the violet tint, although at first marked, quickly disappears. Passing on to vegetable oils, olive gives first yellow, changing to an orange and brown at the centre where the drop of acid first fell, surrounded by tints of a gray and smoky colour, but never with a shade of blue or lilac. By stirring, the oil becomes of a brown to gray colour.

Almond oil resembles olive oil in its reactions, but the surrounding tint is pale gray, and the yellow has a green shade; stirring the acid and oil affords a dirty green.

Sessamum, or Gingilie, gives first a yellow, turning in a few minutes to orange, then brown, with edges of a purple tint, in the course of half-an-hour.

Linseed oil becomes at first rich chesnut brown, and soon coagulates into a hard spot. By stirring, it at once thickens, and acquires a brown-black.

Hemp-seed oil affords nearly the same indications as the above, with, however, a greenish yellow tint at the edges of the acid; and acquiring, if stirred, a greenish brown.

Cocoa-nut shows first a pale purple-brown, gradually darkening; and, if stirred, first an ochre-brown, then deep violet-brown.

Raw rape-seed oil first becomes green, and after ten minutes' time the tint deepens, finally becoming olive-green, or greenish brown; the edges having a bright green colour. On stirring, the tint is bluish green, and at last olive-green.

Poppy oil first affords a lemon colour, becoming darker in spots. The surrounding portion commences with a rose tint, passing successively into violet and violet-blue; at last becoming dark brown. The latter tint occurs if the oil be stirred together at first with the acid.

Nut oil resembles olive oil in most respects, becoming, however, more rapidly brown, the gray edges changing to olive-green. By the method of stirring, the oil runs into clots, and turns to a dirty brown.

Oleic acid changes to a sepia brown, becoming at last nearly black.

The authority from whom the preceding remarks have been in part quoted, observes, that when the sulphuric acid is diluted with a third of its bulk of water, olive, almond, and castor-oils show but little action; whilst poppy, orange seed, and mustard, become dirty brown; gingilie, mauve yellow, with a pink border; linseed, brown; rape, green; cocoa-nut, and refined rape, pale purple-brown; sessamum, lavender, oleic acid, dirty brown; sperm, pale lavender; cod-liver, rose, passing into rich violet, and then into brown; common whale, black-brown; seal, dirty brown; and tallow into blackish brown.

Chromic and nitric acids being both strong oxidating agents—or, instead of chromic acid, a saturated solution of bichromate of potash in sulphuric acid—have both decided actions on oil. Nitrous acid, and a solution of nitrate of mercury, are similarly distinctive in their indications. According to MM. Behrens, Guibourt, and Reveil, a mixture of equal parts of sulphuric and nitric acids, affords an excellent means of detecting adulteration. Equal parts, about a quarter of a fluid ounce, of the mixed acids and the oil are to be used, when the following effects are at once produced:—

Sperm oil . . .	gives	orange.
Seal	,,	orange-brown.
Cod-liver . . .	,,	pinkish violet.
Tallow or Neat's-foot	,,	dirty brown.
Olive	,,	light yellow.
Almond . . .	,,	peach-blossom.
Colza	,,	reddish brown.
Poppy	,,	brick-red.
Gingilie . . .	,,	rich orange-brown.
Rape-seed, raw .	,,	orange-red, and then dirty green.
Rape-seed, refined	,,	yellow-red, and then purple-brown.
Cocoa-nut . . .	,,	pale orange-red.

According to M. Penot, a saturated solution of bichromate of potash in sulphuric acid,

affords, with one drop of it to twenty of oil, and stirred together, the following results :—

Whale oil	brownish red clots on brown ground.
Cod-liver	dark red.
Tallow	reddish brown.
Neat's-foot	brownish red spots on brown ground.
Olive	brown.
Almond	yellow in small lumps.
Hemp-seed. . . .	yellow in clots on a green ground.
Rape-seed	
Poppy	
Nut	brown clots.

There is no doubt that the colours produced on the oils are due to the action of oxygen in the acid, under the circumstances stated; and this points out the varying chemical constitution of each of them. We cannot help remarking, that whilst the preceding modes of testing are very ingenious, they are liable to several sources of error, and must therefore be considered as not to be absolutely depended upon under all circumstances, although, doubtless, excellent as collateral or confirmative evidence.

By the peculiar action of sulphuric acid on oils, a method has been devised for their purification. About one-hundredth part by bulk of acid to that of oil is sufficient for the purpose ; but for oils that clot, the acid requires the addition of one-half its bulk of water to moderate the action of the process. In either case the concentrated or dilute acid is added little by little, abundant stirring accompanying each addition, so as to mix the acid and oil completely together ; and the stirring is continued for some hours after the last portion of requisite acid has been poured in. The clots formed by the action of the acid on the impurities of the oil eventually subside to the bottom of the vessel. The oil then becomes almost colourless, when it is run off into proper vessels, and boiled, with stirring, in half its bulk of water, which removes the acid. Of course, alkalies could not be used to neutralise the free acid, as they would at once decompose the oil, and form various combinations of oleates, stearates, &c., as already explained. The oil is then rendered sufficiently pure for burning. We shall subsequently find that sulphuric acid is of extensive use in the preparation of stearine, and also in the rectification or purification of paraffin oil.

Speaking here of the purification of oil generally, we may add that numerous processes have been devised for the purpose, as filtration through animal and other charcoals, to remove also dark colours, which is against the sale of the oil in the market; bleaching by air, light, chromic acid, chloride of lime, &c. The cause of the impurities, both of animal and vegetable oils, may be generally assigned—first, to their source ; and, secondly, the mode of production or manufacture. In vegetable oils, vegetable acids, sugar, colouring matter, gum, &c., may be expected ; and, in animal oils and fat, albumen, shreds of skin, rancid oil, &c. ; and all the processes that have been invented or adopted, have for their object the removal of such impurities, as being prejudicial to the burning and other qualities of the oil. Some of them may be detected by the taste and smell ; and it is a common practice, on the part of large buyers and brokers, to put a small portion in the mouth, when many impurities, and, frequently, their cause, may be detected.

Besides the chemical tests that we have mentioned as distinctive of oils, and detective of their impurities, many others have been devised of a mechanical character, especially in regard to their fluidity, and fitness for lubricating purposes. Yet, as a good lubricating oil will necessarily be, on an average, a good burning oil (because, in both cases, fluidity and freedom from ready oxidation are requisite), it may be desirable to notice some of the methods that have been proposed.

The test applied by McNaught and some others, is that of directly finding to what extent the oil diminishes or prevents friction ; the latter source of resistance to mechanical force affording indication of the value of the oil as a lubricant for the bearings of machinery.

Mr. Nasmyth's oil test is exceedingly ingenious, and consists of comparing the rate at which any number of different oils travel down an incline, the length of distance and shortness of time being the actual test ; because, of course, that oil which travels fastest, and the greatest distance in the same time, must have first the greatest fluidity. But it does not always follow that this will continue, for the oxidising action of the atmosphere may eventually thicken it, and so, as already pointed out in respect to drying oils, convert it into a solid mass. According to Mr. Nasmyth's plan, a perfectly horizontal plate of iron, six feet long, and four inches wide, is furrowed by six separate and smooth channels, lengthwise. The end is then tilted up, so that the total fall in six feet shall be one inch. At the raised end an exactly equal quantity of each oil to be tested is simultaneously poured into the top of a separate channel. They will thus run down, side by side, to the lower end of the plate. The oils having been all poured in together, commence the descent on the surface of the iron. Some of the worst oils will begin to flow freely downwards ; but, after the lapse of a few days, their progress is stopped, owing to coagulation by the oxidising action of the air. Other oils, apparently more viscid, and slower in motion at first, will, eventually, tortoise and hare-race-fashion, pass those that had freely flowed down the plane. Linseed oil, for example, rapidly passes down on the first day of trial; whilst sperm, at the end of nine days, will have travelled five feet eight inches.

As it is evident that the same conditions subsist in the lamp as in the bearings of machinery, both requiring fluidity, and, at the same time, equally losing that fluidity by heat and oxidation, the following table will be of interest in connection with our subject. It indicates the daily passage down the plane in nine days, the number at the head of each column indicating that of the days of trial :—

Nasmyth's Test of Oils.

Name of Oil.	1		2		3		4		5		6		7		8		9	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Best sperm . . .	2	8½	4	2	4	5¾	4	6	4	6	4	6	4	6½	Staty.		—	
Common sperm . .	1	7	3	9	4	6¾	4	11	5	1½	5	4	5	6¾	5	7¾	5	8
Galipoli . . .	0	10¼	1	2¼	1	6	1	6½	1	7⅝	1	8¾	1	9	1	9¼	1	9½
Lard	1	10¼	0	10½	0	10¾	0	10¾	0	11¾	Staty.		—		—		—	
Rape	1	2½	1	6¼	1	7	1	7⅛	1	7¼	1	7¼	1	7¼	1	7¾	Staty.	
Linseed . . .	1	5½	1	6	1	6¼	1	6¼	1	6¼	1	6¼	1	6¾	Staty.		—	

Of course, in adopting the test many precautions must be taken. If dust accumulate on any one channel more than another, it will have two precisely opposite effects. It will assist the flow of the most fluid oil, by the capillary attraction it generates or affords; but, on the other hand, a readily oxidisable oil, as linseed, &c., will be more quickly acted on by the atmospheric oxygen, and, consequently, it will more rapidly coagulate. Again, if by any accident the temperature of one part of the plate exceed that of another, the additional heat will cause greater fluidity, and so cause error in the application of this test. For reasons already stated, paraffin oil affords an excellent lubricator, as is easily proved if submitted to the above test.

Mr. Tomlinson has suggested a very ingenious test, which, however, we can do little more than name; because, to explain its philosophy, we should have to enter into a description of some most interesting discoveries he has made in reference to the motion of certain fluids and solids in other fluids; as, for example, of alcohol or ether dropped into water or camphor in spirit and water. His method is, to drop the oil to be tested into a perfectly clean glass holding water in a completely undisturbed condition; and by noticing the peculiar form and general mechanical arrangement that the oil takes on the fluid surface, the nature of the oil, and even its adulteration, may be judged of. For a full description of the plan, with drawings illustrating the appearance of drops of different oils thus tested, we refer our readers to the *Journal of the Society of Arts*, London, vol. xii. (1863-'64), and at p. 246. According to Mr. Tomlinson, his method seems to give very accurate and plainly judged of results.

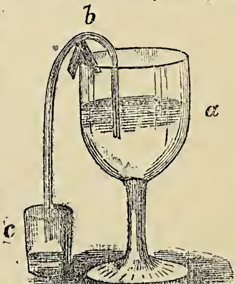
Many other ingenious methods have been devised; but, as they are almost exclusively for the purpose of testing oils in respect to their tenacity, as affecting their lubricating power, we shall omit further mention; concluding this portion of the subject by describing a plan that we have frequently adopted, and that may be advantageously and readily put into use without any expense.

At a previous page (see 635, *ante*), it has been stated that such oils as linseed soon clog up the wick of the lamp, owing to oxidation by atmospheric oxygen, and also by the heat of the lamp, which promotes that change; and it has also been stated, that, in the bearings of fast-running machinery, precisely the same result occurs from analogous—indeed, we may say identical—causes. Hence the following plan suggested itself, and which may be safely trusted in testing oils for both burning and lubricating purposes.

It is evident that the more fluid a liquid may be, the more readily it will obey the law of capillary attraction; as, for example, the wick of a lamp or candle. This may be readily proved by watching that portion of the wick of a candle, especially a large tallow dip, just below the point of ignition, where the fat, being at a high temperature, rushes vehemently up to be consumed. Acting on this principle of capillary action, a test of the fluidity of oils, temporary and permanent, may be had thus:—

Fill, to an *equal height*, as many vessels as there are oils to test, each one having its separate oil. Then loosely twist three or four threads of the best candle-wicks, used by candle-makers, and cut as many lengths as there are glasses, each length being about six inhces long. A separate length, or strand, is then to be introduced into each vessel containing oil, and left there till saturated. This saves time: for if the strands were fixed, as we shall presently explain, in their dry condition, it would require some time to make the oil flow over. As soon as the strands are thoroughly soaked with oil, they are to be arranged as illustrated in the annexed cut, in which only one glass is shown. *a* is a glass vessel, partly filled with the oil under examination; *b* the strand of candle-wick, which is to be hung so that it may enter below the oil in *a*. It is to be kept from the rim of the vessel by inserting a small piece of card or tin in such a manner that both the inside and outside portion may project beyond the glass, which on no account is it to touch. That part

b



a

c

Fig. 439.

between *b* and *c* should be longer than that inside *a*, so that a kind of syphon action may aid the capillary action of the filaments of cotton. Beneath the outer length, *b*, a vessel, *c*, graduated into one hundred, or any other number of parts, is to be placed, to receive the oil as it drops from *b*, which, however, should not be allowed to rest therein, lest it might, before the conclusion of the experiment, get in contact with the oil that has passed over.

The operation of the process is thus :—As many vessels are to be set side by side, and arranged in the same manner as the one just illustrated, as there are oils to be tested, each, of course, being filled with a separate oil. The strands, first dipped into the oil, and then fixed in position, will draw over the liquid from *a*, by *b*, into *c*. Like as in Nasmyth's test, perhaps the worst oil may flow over quickest at first; but as the oxidising influence of the atmosphere goes on, the fibres of the cotton will get clogged. The value of each oil, in regard to its fluidity, will depend on the amount drawn over in the course of a few days ; and the quanity thus run over will be at once indicated by the graduation of each vessel, *c*, and the whole of the oils become thus simultaneously tested. It is best to cover the tops of each glass with paper, that must not touch the candle-wick strand, for the purpose of keeping out dust, and preventing too free access of air in the large vessels.

As a general rule, the oleine, or true oil of oils, fats, and vegetable butters, far predominates in quantity beyond the solid, as stearine, palmitine, &c. Palm oil, for example, contains about 68 per cent. of oleine, and 32 per cent. of palmitine. Cocoa-nut oil has about 70 per cent. of oleine, and 30 of cocine. Generally speaking, the oleine ranges from 61 to 90 per cent. in solid fats, butters, and fat oils. As already pointed out, the proportion of stearine, &c., is a matter of considerable commercial importance in all fatty substances used for the manufacture of candles, if the solid portion is to be extracted for that purpose.

In respect to the amount of light that various oils give off during combustion, great variety exists, similar to what has been already described in reference to the illuminating hydrocarbons, afforded as gas by different kinds of coal. But in the case of oils and fats the cause is entirely different. In coal distillation, a large quantity of the material, generally about two-thirds, on an average, is left in the retort as coke. At p. 572, *ante*, a table has been given, showing the amount of coke thus produced by various kinds of coal ; where it will be seen that, in respect to coke production, Boghead approximates nearest to the condition of oil, which, of course, leaves no residue, but burns away entirely. This is owing to all the hydrogen and oxygen in oils and fats becoming hydrocarbons, except a small portion that escapes into the air unconsumed, and in the form of vapour. The peculiar pungent smell that is noticed then, and also on blowing out either a lamp or candle-flame, is due to the production of a vapour compound called acroline, resulting from the decomposition of the oil by heat. The most perfect form of oil for combustion is paraffin ; for, to all intents and purposes, it may be regarded practically as condensed olefiant gas, which, as already pointed out in our previous pages, is *the* source, *par excellence*, of the illuminating power of all kinds of coal-gas.

The products of the perfect combustion of all kinds of oils and fats, whether in the form of lamps or candles, are only water and carbonic acid, as already mentioned. The production of carbonic acid may readily be proved by a very simple form of apparatus, easily constructed, and which is illustrated in the annexed cut. A

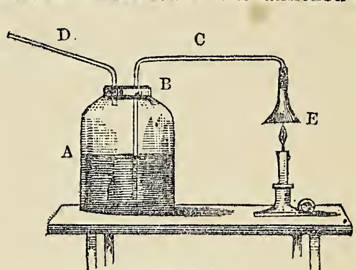


Fig. 440.

is a glass vessel, fitted air-tight with a bung at B, into which two glass tubes, C and D, are also fitted air-tight. The tube C reaches to the *bottom* of A, which is to be partly filled with lime-water ; whilst the other end of C is extended and fastened to a funnel, E, suspended over the flame of a candle. One end of the tube, D, should just enter into the vessel A, but no further. If the mouth be placed at D, and air be drawn out of the bottle A, the atmospheric pressure will drive in air together with the products of combustion of the candle, and these will bubble through the lime-water in A : but with one exception ; that is, the carbonic acid produced by the combustion of the candle will be retained by the lime-water; for it will unite with that earth to form chalk. As this is produced the lime-water will lose its brilliant transparency, and become milky, proving that carbonic acid is a product of the combustion of a candle. If the tube C be partly filled with fused chloride of calcium, or, what is still better, if another tube so filled be fixed between C and the funnel or the jar, the water produced may be collected, and thus both the products of combustion will be simultaneously obtained.

We have already entered so largely into the question of the vitiating effect of illuminating agents, at p. 570, *ante*, where a table of the relative producing power of various light-giving materials, in respect to tallow, oils, and gas, has been given ; and, subsequently, at p. 628, have dealt with the question of ventilation, that it will be unnecessary again to deal with either subject. The remarks on ventilation, at the page last referred to, are general in their application for that purpose, in the presence or absence of the use of any illuminating agent. We shall, therefore, pass on to describe the various sources of the oils, fats, butters, &c., derived

from the animal, vegetable, and mineral kingdoms; explain the methods of extracting or preparing them; and then point out their chief uses, and the various methods of manufacture requisite for that end.

Sources of Fats, Oils, Etc.

Every attempt that has been made to form a distinctive barrier between each of the kingdoms—animal, vegetable, and mineral—has, more or less, associated in its characteristics the special products of one, and the absence of the same in another; and, for a time, such a distinction was maintained, only, however, to be shown as groundless by future discoveries. At one time, for example, the power of locomotion was considered as essentially an animal quality; but that idea was exploded. On the other hand, starch cells were thought to be exclusively the property of the vegetable kingdom; but recent discoveries have proved, that portions of the body that never could be reached by food, except in the form of blood, exhibit substances analogous to, if not identical with, starch. Still locomotion and starch may be considered as highly designative of vitality, and so separating the animal and the plant from the mineral.

But this distinction is but partial; for the subject we have now to deal with—the sources of oils, fats, &c.—brings us to the conclusion that these substances are products of all three kingdoms. Indeed, within the last few years, the numerous substances obtained from coal distillation, as already detailed, *ante*, at p. 598, bring us to perceive a much closer connection between animal and inanimate matter than could possibly have been imagined. A few of such connective links may here be noticed. Thus ammonia is equally the product of coal, animal and vegetable matter. Aniline is afforded by the urine of animals, the indigo of the plant, and the tar of coal distillation. In respect to oils, they are equally producible from the animal, plant, and mineral. In fact, the further we press our inquiries into the secret processes of nature, the more we become convinced, that the distinctions we assign to her operations are merely conventional and ephemeral, and they become gradually dissolved away as mist before the rising sun.

Of all the products of the three kingdoms unitedly, the oils are by far the most abundant and general. They have no organic condition, being merely fluids enclosed in cells, or membranes, in the plant and animal, and a secondary product of the mineral. It is this absence of organism that permits of their universality, and makes them a product of each division of existence. All of nearly the same constitution, chemically speaking, and generally having all but identical properties, they may be substituted for each other for almost every purpose to which they can be applied.

In describing the various kinds in general use, we shall commence with those derived from the animal kingdom, as being the highest in the scale of existence.

Until recent years tallow was the chief fat used for illuminating purposes in civilised countries; which, doubtless, arose from the fact that, at all ordinary temperatures in Europe, it retains a solid condition—at least in those seasons of the year when it would be employed for lighting purposes; and also on account of its abundant production by domestic animals in our quarter of the globe.

The best tallow is obtained direct from the animal, especially that enveloping and adjacent to the kidneys—that of mutton being the firmest. But this would be far too scarce for all commercial purposes; hence the fat of the whole animal, generally the ox and sheep, is used indiscriminately. In Europe, the flesh of those animals is so universally eaten, and the demand for it so great, that the fat is sold merely as an accidental product, left after the meat is cut into joints. But in many countries—Australia, America, &c.—the animals are slaughtered for the skin, and then boiled for their tallow; the carcass being of little value, owing to the comparative fewness of meat-eaters, and cheapness of fodder. Of recent years, because of the high price of meat in Europe, it has been attempted to introduce the flesh thus left after boiling, or as separated from the fat before boiling; and a good deal has been imported, at a nominal price, for that purpose from South America; Australia, &c., especially in the form of canned meats.

A large source of tallow exists in the dripping that falls from meat during the process of cooking, and which is technically called kitchen-stuff. But, like the fat as taken from the animal, it is far too impure to permit of immediate use after melting; and hence both require purifying—a process known to the tallow trade by the name of *rendering.*

This is effected in various ways. The old-fashioned method was that of melting the fat in a copper, by which water, &c., were driven off. As the fat became liquid, the shreds of skin or membrane that enclosed the fat in the live animal became separated, together with blood and other impurities. These, as they collected, were skimmed off, and, being submitted to pressure, formed the greaves for dogs and poultry. Another plan, which prevented the burning of the fat, and its boiling over, when heated by a naked fire—a frequent cause of extensive conflagration—was that of blowing steam into it. Still better is the method of treating it with dilute sulphuric acid, in the manner already described as used for purifying oil, at p. 637, *ante;* for thus the impurities become decomposed, and settle at the bottom. The membranes, however, are first removed for the purpose above mentioned, for they form a product that diminishes the first cost of the tallow considerably to the candle-maker.

Since bone-boiling has become so general, and the use of bones as "superphosphate," bone-ash, crushed bone, animal black, &c., has become so extensive, another large source of fat has been introduced by bone-boiling. The fat is removed by heating the bones with steam in large boilers:

it is not, however, so well adapted for candle as for soap-making. The fat of horse-bones is largely produced thus as a material for the soap-maker.

The term tallow is usually confined to the fat of the ox and sheep; but occasionally that of the pig is introduced, to the disadvantage of the candle if its tallow be made with that fat as part of the compound. Usually, the lard or pig fat is too much required for domestic and confectionery purposes; but still much lard oil is produced by the extraction of the stearine. The latter is mixed with that of ox and sheep stearine for candle-making; whilst the lard oil, or oleine, is much employed as a lubricant, and for illuminating purposes.

It has already been stated that, from all these fats, stearine and margarine are separated as solids, leaving the fluid oleine. The manufacture of these products on the large scale, for candle-making, will be subsequently entered into.

A popular mistake ranks many creatures inhabiting the sea as *fish*, to which they have as much title as a herring has to be called a quadruped. All our *chief* sources of oil from the inhabitants of the ocean, are those found in animals that give suck, and produce their young alive; and a female whale is of exactly the same order, in natural history, as any of the quadrupeds of the land; and, indeed, saving the pride of humanity, we may add that physiological science would reckon the female sea-monster in the same rank as even woman; the characteristic being, in all cases, the possession of breasts, or *mammæ*, with teats, milk-organs, &c. Hence whales, dolphins, the porpoise, narwhal or sea-unicorn, sea-cows, the dugong, &c., are all ranked amongst *mammalia*, or suck-giving animals, equally with the cow, mare, sheep, &c., &c. An exception, as regards *fish*-real, will be found in the cod, herring, sprat, and many others, of which due notice will be presently taken.

For about ten centuries that are known certainly (and how much longer cannot be ascertained), the pursuit of the whale in the northern seas of Europe has been carried on for the sake of its blubber. The whale fishery was, about thirty or forty years ago, one of great importance to this country; and a large fleet of ships was employed. Sent from our eastern ports, from Hull to Aberdeen, the ships yearly put to sea about the period of breaking up of the northern ice, to pursue the whale fishery in the seas about Spitzbergen, Iceland, the eastern and western coasts of Greenland, in Davis' Straits, and generally from Norway to Labrador; and in North America, further north, in Baffin's and Hudson's Bay. Here the Greenland whale (called, in natural history, *Balæna mysticetus*, sub-order *Cete*) abounded; but, of late years, the fishery has greatly fallen off, arising either from over and destructive fishing, or from the whales having sought other quarters further northward, and, practically, from danger of ice and icebergs, out of the reach of man. A large proportion of the whales that are wounded are not recovered—sometimes so many as 50 per cent. escaping—a circumstance not only causing loss of time and disappointment to the whalers, but injuring the fishery; for, generally, the instinct of the whale seems to lead him to shun proximity to a dead or dying companion, although whales are constantly gregarious, and apparently even sociable in the Arctic seas. On this point we need scarcely remind our readers of many interesting and touching anecdotes of the whale for her young, founded, not on imagination, but on so high an authority as the late and lamented Scoresby.

The blubber of the whale is a kind of fat-lining, extending, from the external skin inwards, to a depth of from eight to twenty inches, according to the size and fatness of the animal. The blubber of a large whale will have an average weight of thirty tons, producing from twenty to twenty-five tuns of oil.

The blubber, which is really the true skin of the whale, is a soft unctuous substance, held together by fine membranes. It is removed from the animal by being cut out by knives—an operation called "flensing;" and the lumps are stowed away in casks until the vessel returns home. It is first rendered or purified by draining in vessels furnished with a wire grating. The blubber being pressed on this, parts with the fat, which runs through into a receptacle placed beneath, whilst the membrane that previously enclosed the fat, is retained by the grating. The oil, after settling, is then heated, so as to coagulate most of its impurities, which settle down; and the clean oil is then drawn off into casks. Or, at times, the blubber is allowed to putrefy, when the oil is released in a fluid state, to be purified as above. In this condition it enters commerce as *whale oil*.

The southern seas, also, abound with whales of the same family as that we have described. "The southern whale, *B. Australis*, has the head much smaller, in proportion, than the Greenland whale; in the latter the head forms nearly one-third of the length of the body; whilst in the southern species it is not more than one-fourth. Its size is nearly equal to that of its northern relation, the usual length being about fifty feet, although specimens of seventy feet long have been mentioned. According to the Japanese, however, the larger whales of this species attain a length of 100 feet; but this is evidently an exaggeration. The southern whale is an inhabitant of the great Southern ocean, where it generally keeps near the coasts, and in rather shallow water, extending up the shores of the Pacific to Japan and Kamtschatka; and on the coasts of America, in the Pacific, as far as the United States. It is also abundant on both shores of the African continent. The females visit the bays on the coasts frequented by them in the month of June and July, for the purpose of producing their young; and it is then that they are taken in considerable quantity for the sake of their oil. The principal fisheries are on the coasts of New Zealand and South Africa; but, from the victims being always of one sex, their number is

rapidly diminishing." At the present time, much of our whale oil is derived from this source; but, as just stated, the stupid cupidity of man is gradually diminishing, with unerring and fatal certainty, both our northern and southern sources of whale oil.

Sperm oil, the best of all animal oils, is also produced by a species of whale, the *Physeter macrocephalus*, or Cachalot, which is generally distributed through all the oceans and adjacent seas, but whose *habitat* is chiefly in the southern hemisphere. The males of this species are of great size—from sixty to seventy feet in length, and thirty to forty in circumference; the females, however, not averaging more than half that size. The blubber affords the best kind of whale oil; the sperm kind being taken from the fluid portion of the matter in the head. This matter consists of an oil, the *sperm*, and of a solid, known in trade as *spermaceti*. Cold and pressure separate the two; and the oil is purified by sulphuric acid, in the manner already described at p. 637, *ante*. Spermaceti is extremely valuable for making the finest kind of candles, sold as sperm, which have a beautiful semi-transparent appearance, and, as already noticed, are the standard for photometrical experiments. Spermaceti has also extensive uses as an ointment, &c. We may here notice, that *Ambergris* is a morbid concretion of the sperm whale, either of the stomach or gall-duct, analogous to the calculi of the human subject. It is usually found floating on the water, having been disengaged from a decomposed carcass. It is of great value. being largely employed in perfumery.

Of the same natural order, *Cete*, the dolphins, *Delphinidæ*, are a source of much oil. The porpoise, *Phocæna communis*, is abundantly distributed in the northern seas. Even in the Thames they may be seen by hundreds; and, indeed, most of our rivers, more or less, abound with them. On the west coast of Scotland it particularly abounds. The *round-headed* porpoise, *Phocæna melas*, is very gregarious, swimming about in large flocks, sometimes as many as 100 to 1,000 being together, and forming a lucrative catch for the Shetland and Iceland islanders. In Shetland, this species of porpoise is termed the "Ca'ing," or driving whale: to explain this we may refer to one of its peculiarities. "In the capture of these animals, the boatmen are greatly assisted by the strong instinct which prompts the porpoises to follow one another like a flock of sheep; so that when the leader of the flock has run upon the beach, all the rest are pretty sure to follow his example. To drive them on shore, all the boats in the neighbourhood go out and surround the shoal, upon which they gradually close until the victims are stranded, when they are quickly despatched; and the sea is frequently tinged with blood during one of these massacres. The bellowings of these animals are also described as fearful." Generally speaking, the dolphin family is abundant in all seas, &c. The oil is of excellent burning properties; and the ordinary species yield about eight or ten gallons for each animal.

The narwhal, or *sea-unicorn*, is a species of dolphin. It is an inhabitant of the northern seas, and is remarkable for possessing a tusk of ivory, from six to ten feet long, projecting from the centre of the upper jaw. This tusk, in most respects, resembles that of the elephant, especially in its growth or development. From this and the walrus no supply of oil worth notice is obtained, at least so far as we are concerned. Amongst the *Sirenia*, or herbivorous cetacea, the manatees, or lamantins, and the dugong, *Halicore cetacea*, are the chief oil-producers; but neither is of commercial importance. The oil of the dugong has, of late years, been substituted for cod-liver oil to a limited extent; whilst the flesh and oil of the manatees are much esteemed in South America. Both species mostly frequent the seas of warm climates. They feed entirely on aquatic plants; and whilst, externally, they are related to the whales, their general organisation, strange to say, allies them with elephants. These curious creatures often support themselves in an upright position, when, with the upper part of the body out of the water, their long whiskers, and the breasts or *mammæ* of the female, they fully justify the stretch of imagination that has led to the belief in tritons, sirens, mermen, and mermaids, in all ages of man's history; hence the name of the sub-order, *Sirenia*.

The walrus, above mentioned, in many respects connects the preceding with the seal tribe, an important source of animal oil. Although properly belonging to the seal, its food is chiefly herbaceous, like that of the *Sirenia*. Like the narwhal, again, it has tusks, which furnish beautiful white ivory. We here repeat it for the purpose of introducing seals, *Phocidæ*, the most abundant species of which is the common seal, *Phoca vitalina*, that is generally abundant around the northern coast and islands of Scotland; but in immense profusion on the more northerly coasts of Europe and America, and the interjacent ocean. With the Greenlander the seal is as valuable as the reindeer of the Laplander, the camel of the desert, or the cocoanut of the southern islands; for it furnishes men with food and clothing, the skin being of great value, the flesh good eating, and the oil largely sought after. It is one of our chief animal oils, and is excellent for burning. The oil is readily obtained by boiling down the fat as taken from the animal, and may be purified by any of the processes already described.

We next turn to what are really *fish oils*, as distinguished from those which, obtained from the *mammalia*, we have, for the sake of clearness, called "*animal*" *oils*; for, although that term is universally applied to them, it is just as applicable to oil obtained from every member of the animal kingdom. Every fish contains a certain proportion of oil in its constitution, just as the mammalia possess fat; but the amount and locality of the oil greatly vary. The cod is mostly valued for the oil extracted from its liver, now so enormously in demand as a remedy in various forms of scrofula, phthisis, &c. On our own coasts, the herring, sprat, and pilchard are the most abundant producers of oil. It is

extracted by pressure. Generally speaking, real fish oil is not fit for lamp combustion, being liable to thicken. The kinds, however, we have named, except the cod-liver, are all cheap, and answer well for out-of-door or other purposes, where smoke and smell are not objectionable.

It will be thus seen that our sources of oil from animals are as various in quality and quantity as they are in number. The best of all is evidently sperm, as already shown by the oil-test table, given at p. 638, *ante*. But much depends on the mode of purification; for all animal fats and oils are mixed with peculiar principles or compounds, that are generally diffused throughout the bodies of the creatures from which they are obtained. They either become dissolved in, or, at all events, mixed with such fats, and tend always, by their putrefaction, and frequently by fermentation, to injure the oil, by causing thickness, unpleasant smell, or other objectionable qualities, that are sometimes not to be got rid of.

We next turn to vegetable sources of oils, "fats," "butters," or "tallow."

These are exceedingly numerous, and produced in almost all countries, between a latitude of fifty degrees on either side of the equator; or, perhaps, in respect to the south of the line, might be so produced; for so little land lays in that portion of the globe. At the same time each climate has its peculiar plants, that may be, or are, oil-producing. Thus, in our island, the seeds of species of *Brassica*, the cabbage tribe, afford colza, rape, &c. Linseed and hemp-seed are also oil-producing. Further south, in Europe, as in the south of France, Italy, &c., the olive and almond are chiefly cultivated for the purpose of obtaining oil; and, in tropical regions, various species of the palm tribe, with others shortly to be described, are cultivated, or grow natural, and become sources of oil for use in those climates, and export to our own and other European countries.

Almost every part of plants affords oil; that is, if the entire range of the vegetable kingdom is included in a general view. From "nuts" we have the Brazil, cocoa, walnut, almond, &c. From "seeds," rape, colza, sunflower, poppy, &c. Leaves are frequently productive of vegetable wax. The fruit affords olive oil. The trunk of the wax palm is another source of fat or wax. As a rule, however, the fruit—that is, the seed or nut—is the most productive of oil.

With respect to the variety of plants unconnected by any special botanical relationship, it is certainly very great. It would seem, in fact, that fixed and volatile oils are all but characteristic as a product of vegetation, so widely are they afforded. This is not by destructive distillation, as in the case of coal, but simply through mechanical means, as pressure or bruising; and frequently, also, the extraction of oil is effected by heat, which, bursting the membrane, sets the oil of the seed free.

Mostly the oils of plants are obtained by pressing or pounding them. By the former method, the seed having been first crushed so as to break the external covering, and thus exposing the inner substance, is put into hair-cloth bags, and compressed with enormous force in a hydraulic press, by which the oil is driven out through holes in the lower part of the plate of the press; and the process is repeated until all the oil possible to be extracted has been obtained. One form of oil-mill, especially for linseed, is that of vertical pillars of wood, the lower end of which is shod with iron. These pillars are caused to rise and fall vertically by a cam motion, driven either by water or steam-power. The bruised seed is placed on a kind of firm table or stand, in a hair-cloth or other porous bag; and by the repeated fall on the bags of the pillar or ram just mentioned, the oil is driven out. "In the best mills upon the old construction, the cakes obtained by the first wedge-pressure were thrown upon the bed of an edge-mill, ground anew, and subjected to a second pressure, aided by heat now as in the first case. These mortars and press boxes constitute what are called Dutch mills. They are still in very general use, both in this country and on the continent; and are, by many persons, supposed to be preferable to the hydraulic pressure."

In the case of the olive, which supplies its oil from the fruit, the latter is reduced to a pulp; and this is put into coarse linen bags, which, on being submitted to moderate pressure, yield up the oil. That first drawn is the purest and best; the inferior quality of olive oil is obtained by a second pressure of the remaining pulp.

Heat always facilitates the expulsion of the oil from any source, because it renders the oleaginous matter more fluid; and hence a distinction is drawn between oil simply expressed or extracted in the cold, and that withdrawn, in part or entirely, by the agency of heat. Hence the distinctions of hot and cold drawn, as applied to many kinds of oil. "The amount of oil obtained in this manner varies with different seeds, and even with the same seeds in different countries and seasons. Walnuts and hazel-nuts usually furnish about half of their weight of oil; poppy seeds, nearly half; olives, about one-third; rape-seed, a third; that variety called colza, about two-fifths; hemp-seed, a fourth; almonds, a fourth; linseed, a fourth; and the seeds of grape, or 'wine stones,' one-tenth." As a rule, oil drawn without the aid of heat is better for every purpose to which it is usually applied, as heat tends to the retention and development of several impurities already mentioned; and frequently, or, indeed, generally, causes ultimate rancidity.

The cake that is left after the extraction of the oil is not wasted. On the contrary, it becomes a valuable food for cattle, for which it is considered as very fattening. In Holland, however, where oil-extraction from linseed, &c., is extensively carried on, Barlow observes, comparing the modes adopted in other places where much oil is lost—"The Dutch, however, take more pains; they add no water to the paste of the first stamping, which, they say, greatly lowers the quality of the oil. The cakes which result from this pressing, and which are sold as

food for cattle, are still fat and soft; and the Dutch very commonly break them down, and subject them to the pestles for a second stamping. This reduces them to an impalpable paste, stiff like clay, which is lifted out, and put into a chauffer-pan; a few spoonfuls of water are then added, and the whole is kept for some time at the heat of boiling water, and carefully stirred during that time. Thence it is shifted into the hair-bags of the last press, subjected to the greatest pressure, and a quantity of oil of the lowest quality is obtained, sufficient to give a satisfactory profit to the miller. The cake is now perfectly dry, and hard like a piece of board; it is, however, useful to the farmer, to whom it is sold. In this way there is a great quantity of oil obtained, which would be otherwise lost; and there are small mills in Holland which have no other employment than that of extracting oil from cakes, which they purchase from the French and Brabanters, after passing the process of their mills—a clear indication of the superiority of the Dutch practice. * * * The Dutch have been generally considered to excel in this description of manufacture; and the nicety with which that industrious people conduct the whole business, is remarkable."

In hot countries, the mode of obtaining oil is facilitated by the temperature of the atmosphere. Various methods have been adopted, but, generally, they form only special applications of those already mentioned.

Having thus described the modes adopted for extracting vegetable oils, it may be added that their purification is generally conducted, when necessary, after the manner usual with animal oils (already described in our preceding pages), with such modifications as special circumstances may require to be followed.

At the present time, about fifty different sources exist whence the oils of commerce, used for lamps, candles, and lubricating purposes, are drawn. All the vegetable fats come to us from warm climates, where, however, owing to the higher temperature of the air, they are naturally fluid, becoming congealed on their voyage hitherward, or on arrival in the docks or warehouses. It is impossible to classify them under any number of heads, short of becoming as diffuse as the plan we shall follow—that of referring to them in alphabetical order. They are as follow :—

One of the finest oils produced by any plant, or in any country, is *almond oil*, afforded by the seeds of the *Amygdalus communis*, order *Rosaceæ*, sub-order *Drupaceæ*. The tree is a native of the south of Europe, where it is extensively grown. Our climate is too changeable to admit of the general ripening of the fruit, although we have seen instances, in the northern and southern suburbs of London, in which the fruit has ripened in the open air; and have eaten the nut so produced. Such, however, is a rare case in our uncertain climate. Almond oil is very fluid, thickens very slowly, and is exceedingly valuable in some delicate branches of art—as a lubricator, for instance, for watches and clocks. It is much used in medicine and perfumery; but in this country, like olive oil, is too expensive for burning purposes.

In Morocco, the fruit of the *Arganica sideroxylon*, or rather the kernels of the fruit, are used as a source of oil, which much resembles olive oil. Indeed, the Moors substitute *Argan* oil, as it is termed, for that of the olive, for cooking and burning purposes.

In some parts of Europe, the oil obtained from the mast, or nut of beech, is employed for burning and cooking; but its use is chiefly confined to places where the beech is plentiful.

The ordinary Brazil-nut, the fruit of the *Bertholletia excelsa*, order *Lecythidaceæ*, is very rich in oil, and affords an excellent one. It is exceedingly fluid and limpid, with a slight agreeable odour. It is a matter of surprise that attention has not been more fully drawn to this oil. But the disturbed state of Brazil, and the utter want of commercial enterprise that characterises people located perhaps in the richest spot in the whole world, are quite sufficient to account for the neglect of that and many similar sources of wealth. Recently, however, more liberal measures have been adopted by the government, and foreign capital is being encouraged for investment; and even foreigners have been offered certain privileges if becoming settlers; so that now there is a prospect that this favoured empire may become more prosperous and productive than it has ever yet been. If the enterprise of British merchants has succeeded, amongst the most barbarous tribes of Western Africa, in increasing the production of palm and cocoa-nut oil, Brazil surely cannot long be behind her in following so salutary and profitable an example.

Cameline, or *Dodder* oil, has already been largely employed for burning purposes, in place of colza and rape oils. It is a product of the *Camelina sativa*, order *Cruciferæ*, to which, in fact, the latter also belong. The plant is commonly known as the Gold of Pleasure, and its seeds yield the oil abundantly.

In the South Sea islands, the seeds of the candle-nut afford abundance of oil, that the natives use for cooking and burning. They also form rude candles of the seeds, by stringing them together on sticks. The plant is known, botanically, as *Aleurites triloba*, and it belongs to the *Euphorbiaceæ*, or Spurge order.

The seeds of the *Carapa Guineënsis*, order *Meliaceæ*, are used by the natives of Western Africa as a source of oil, a good deal of which is exported to Europe as carapa, or crab oil. In the south of France it is employed in soap-making.

The cacao nut, the source of "cocoa," the cocoa-nibs, &c., of the shops, contains not less than 50 per cent. of oil. Many of our readers will have noticed its production from the favourite beverage made from the nibs; for on the fluid becoming cold, the oil collects as a butter-like fat. It is obtained from the *Theobroma cacao*, order *Byttneriaceæ*. It is good for burning, but must be distinguished from the following, which has no relation whatever with it.

The ordinary cocoa-nut oil is one of the chief butter-like oils imported into this country; and, in combination with palm oil, &c., is largely employed in making composite candles, and some kinds of soap. It is the production of the ordinary cocoa-nut, used in this country as fruit. This nut is the fruit of the *Cocos nucifera*, belonging to the *Palmaceæ*, or Palm order, and grows abundantly in most hot climates. It produces about 70 per cent. of oleine, good for lubricating purposes, and 30 per cent. of cocine, that can be applied to candle-making. In tropical climates the tree is as plentiful almost as weeds are with us. The extraction of the oil from the inner white lining and kernel of the shell, is effected by any of the methods already described as followed for vegetable oils generally.

Colza oil is well known as having been long employed in the best kinds of oil-lamps. It is produced from the seeds of the *Brassica campestris*, variety *Olifera*, and belonging to the natural order of *Cruciferæ*: it hence belongs to what is familiarly known as the cabbage tribe amongst plants. It has long been a favourite oil. With this we may class rape oil, also a product of a variety of *Brassica*. The oil from either seed is expressed by grinding and crushing, as previously described, and purified by sulphuric acid, in the manner already mentioned at p. 637. On an average the yield of the seeds is about 30 per cent. Rape-oil extraction is an important branch of the oil trade or manufacture.

For many years a most valuable source of oil has been neglected: we refer to that so easily obtained from the seeds of the cotton plant, producing oil in great abundance, and that may always be had almost as a gift; for, as the amount of seed produced by the plant always exceeds the wants of the grower, its accumulation becomes all but a nuisance. Hundreds of tons of valuable oil-producing seed have thus been wasted for many years. It is procured from various species of *Gossypium*, order *Malvaceæ*, being the product of many varieties of the plant, or the fibres of the fruit, on which our largest manufactures in this country so greatly depend. By purification, the dark colour of the oil is converted into one of a light yellow, or amber; and, after the oil has been expressed, the remaining mass forms an excellent oil-cake for fattening cattle.

Gingilie, or Sesamum oil, is obtained from the seeds of the *Sesamum Indicum*, order *Pedaliaceæ*, a native of India, and other warm climates. In its native countries it is largely used for burning, cooking, and anointing purposes. Into Europe it is imported either as oil or in the seed; and, from its comparative cheapness, it is used as a substitute for, and an adulteration of, other oils. The seeds, on an average, yield from 40 to 50 per cent. of the oil.

The ground-nut is another and abundant source of oil. It is the fruit of the *Arachis hypogæa;* and the nuts have the singular property, after growing to a certain size, of bending down to, and burying themselves in the soil, where they ripen; and hence their name. It is said that a bushel of the nuts will yield a gallon of oil. The plant belongs to the Pod, or *Leguminosæ* order, of the sub-order *Papilionaceæ;* and is grown in Europe, various parts of India, and generally in warm climates.

Omitting hazel-nut, the oil of which is chiefly used in painting, perfumery, medicine, &c., hemp-seed is next in order. It is afforded from the seeds of the common hemp plant, the *Cannabis sativa*, order *Cannabinaceæ*, native of temperate climates, and of India, where it is chiefly produced. From its disagreeable smell, its use is mainly confined to the poorer classes of that country.

Linseed oil, although, as previously stated, scarcely suitable to be burned in lamps, on account of its tendency to thicken, may be so used if proper precautions are taken. It is most fit for the inexpensive one-wick lamps, that can be cleaned out daily, and supplied with a new wick at too trifling a cost to be worthy of mention. Its other applications make it of great value; for, boiled with litharge, it affords the boiled oil of the painter and the varnish-maker. The refuse of its crushed seeds is largely sought after by the grazier and farmer, as food to fatten oxen. We have already noticed another and curious application of the oil, being that of so drying and hardening it as to form a kind of floorcloth. Linseed is the seed of the *Linum usitatissimum;* also the source of flax fibre for our linen manufactures: it forms the leading member of the natural order *Linaceæ*.

In some parts of America, especially in the north of the United States (New York, &c.), maize, or Indian corn, has been used as a source of oil for burning. We are not aware, however, of its having been so adopted in this country. Its abundance in America will, of course, there permit of more extended applications; but still it can be equally as well grown in the south of Europe. Indeed, in the East Indian islands and Northern Africa, it has long been extensively cultivated; and should any great value be attached to the oil it produces, its consumption would soon become prevalent. We have not learnt, however, that such is the case.

Some species of *Bassia* yield valuable oils. Thus the *Bassia butyraceæ* affords what is called vegetable butter, which makes excellent soap, and burns with neither smoke nor smell. *Galam*, *Ghea*, or *Shea* butter is the product of the *Bassia Parkii*. It is an exceedingly good article either for the manufacture of soap or candles; and is likely to become much more largely imported as its properties are better known. It contains about 32 per cent. of solid matter, resembling palmitine; and affords 68 per cent. of oleine. In hot climates it is known as "butter;" because, not melting at a temperature less than 95° to 97°, it is there in a semi-solid condition at ordinary temperatures. An oil called *Mee* is produced from the *Bassia longifolia;* and *Naneel*, from *Bassia latifolia*. It is obtained by pressure of the seeds; and is useful for burning and other purposes. All these species belong to the Sapodilla order, or *Sapotaceæ*. Most of the plants so embraced in this order, afford a milky

juice, and many of them produce excellent fruits. Argan oil, already named, is produced by a species of *Sapotaceæ*.

Besides the pungent volatile oil, to which mustard owes its peculiar flavour, it affords a fixed oil of a dark-brown colour, both from the black and white species, *Sinapis nigra* and *alba*. The seeds yield from 20 to 30 per cent.; and, after refining, the oil is frequently used to adulterate colza and other oils.

Under the head of nut oils are hazel and walnut: the plants producing them are familiarly known; and as they are unfit for burning purposes, they may be dismissed with this brief notice.

Olive oil is one of the most important of European oils. It is also of the finest kind, and is largely employed in a variety of ways. In this country it is too expensive to employ generally in lamps; its uses are, therefore, mostly confined to objects of perfumery, medicine, and others in which expense is not regarded. In Italy and other places, where the fruit grows abundantly, the oil is employed for artificial illumination; and the light it affords is pleasingly soft, if properly managed. It is the fruit of the *Olea Europæa*, order *Oleaceæ*. There are two varieties chiefly grown—namely, the long-leaved, or *longifolia*, in France and Italy; and the broad-leaved, or *latifolia*, in Spain. The oil first extracted is preserved for dressing salads, frying, and other such purposes of domestic economy. The subsequently drawn oil, by second and third processes, is of inferior quality, and is used for lighting and lubricating purposes.

Palm oil is one of the most important of the thick oils imported into this country for candle-making, &c. It is produced from the *Elais Guineënsis*, order *Palmaceæ*. The fruit of the palm tree is about the size of a pigeon's egg, and, externally, of a yellow or golden colour. In extracting the oil, the fruit is bruised to a kind of paste with boiling water, when an oil, of an orange colour, separates; which, as it cools, assumes a butter-like consistence. It has a peculiar, and, to some persons, agreeable odour. It contains, on an average, about 68 to 70 per cent. of oleine, and from 30 to 32 per cent. of palmitine; the latter, as previously mentioned, being an important material in the manufacture of composite candles. The refuse of palm oil is converted largely into railway grease, for which it is admirably calculated, and almost exclusively used in this country, as it can take up much water, which, whilst the oil lubricates the axles, to some extent assists in keeping them cool.

We have already briefly noticed, that the consumption of palm oil has had an important moral effect. The palm trees that produce it, abound, on the west coast of Africa, in great profusion; they are, in fact, as native there as the oak in England, or the pine and maple in Canada. On the first introduction of stearine candles, that of tallow was used; but, gradually, it became evident that many products of vegetable life were equally as suitable, if they afforded a substance analogous to stearine in its properties. Such is furnished both by the palm and cocoa tree. We believe, however, that palm oil was the first most extensively used, becoming especially familiar in the manufacture of a firm—Palmer and Co., London. The great popularity of their double-wick candles—that, although at first yellow and unsightly, had the advantage of giving a beautiful steady light, and were self-snuffing—tended greatly to increase the demand for palm oil; and whilst these candles took the place of the old tallow dip, the composite replacing the mould, became also in large demand, and, therefore, equally increased the necessity for a more abundant supply of the oil. Added to this, the discovery of new methods of rendering it perfectly white, raised its value, and enlarged the consumption.

An eminent firm in London accordingly determined on establishing depôts on the African coast, for the purchase and storing of palm oil brought from the interior. It was not long before this had a most beneficial influence in checking and diminishing the slave-trade; as the poor wretches, that would otherwise have been sold to go to Cuba as slaves, became more valuable as a home investment, in raising crops of the palm, or in picking those already existing. We believe that the arrangement has still further extended, and that the firm has become their own growers of palms, employing a large number of blacks, at wages low to the employed, but abundant for the few and simple wants of the labourer. This, then, is by no means amongst the lowest benefits that the discoverers of chemistry applied to manufacture have conferred on man. Pecuniarily, to us, as a nation, the maintenance of a fleet to watch and prevent the slave-trade was one of great annual cost; but by the extension of this system of palm-growth, &c., it is scarcely to be doubted that more good will be eventually effected in stopping that infamous trade, than if our whole fleet were stationed off the coasts and the mouths of the African rivers.

We next, in alphabetical order, arrive at the poppy. It is procured from various species of *Papaver*, but especially *P. somniferum*, of the variety *nigrun*. The oil is used variously in the arts; and is produced in large quantities, by pressure of the black seeds of the plant just named, for the adulteration of more expensive oils. It is largely grown in India for that purpose, but has the same objection which attaches to linseed, and some other oils already described—namely, that of easy oxidation by atmospheric action; and, consequently, of rapidly drying. Hence its use in the hands of the artistic painter.

Sesamum, or Gingilie oil, has been already named in connection with the latter name; and, similarly, Shea butter has been described with Galam, or Ghea oil or butter.

A nut, fruit of the plant *Caryocar nuciferum*, and order *Rhizobolaceæ*, a native of South America, affords an oil, there used for a variety of purposes. The fruit is generally known as the Souari-nut; but, we believe, the oil is not in any way employed in Europe.

The seeds of the sunflower—the *Helianthus annuus*, order *Compositæ*, and well known as a common garden plant, conspicuous by its large yellow blossom—have been largely used, of late years, for the production of oil. It is, however, chiefly confined in use to making fancy soaps : the refuse of the pressed seed is valuable as food for cattle, like that of linseed, cotton, and others.

Under the name of Vegetable tallow, a variety of solid fatty products may be included. The term "tallow," although evidently a misnomer, is frequently applied to solid white unctuous substances, from their great resemblance to that product of animals. Some fine specimens of the kind may be seen in the Museum of Economic Botany, at Kew ; where, indeed, all those oils, fats, &c., already described, are similarly illustrated, together, in most cases, with portions of the plants from which they are obtained. Many Indian, Chinese, and African plants produce such substances. The *Pentadesma butyraceæ*, order *Gutifferæ*, a native of Sierra Leone, is of this kind. The Chinese produce a considerable quantity of vegetable tallow from the seeds of the *Stillingia sebifera*, order *Euphorbiaceæ*. It is applied to making candles, especially used by them for illuminating purposes in their public festivals. The *Brassia butyraceæ*, already described as one of the order *Sapotaceæ*, has its butter-like product occasionally termed vegetable tallow.

Walnut oil has been already mentioned in connection with "nut oils." The nuts afford about one-third of their weight of oil, which is much employed to adulterate more expensive oils.

This may be considered to close the alphabetical list of the chief oils employed for illuminating purposes. For the present we shall defer mentioning the sources of vegetable wax, as they will be more conveniently considered in connection with the preparation and manufacture of wax for candles.

Although the preceding list is greatly extended, it far from exhausts the entire sources of the vegetable kingdom in respect to the production of oils. These, like opium and india-rubber, are almost universally diffused ; but, in all cases, the value of any product, commercially, must be reckoned according to the cost of its production. As it is often observed, we may pay too dear for gold ; and so, in reference to vegetable products, their actual value is modified, in commercial importance, just in proportion as the cost of their production increases.

It is remarkable that, although for at least a century or two back, a large number of such products must have come under the notice, at least in India, of intelligent persons, scarcely any application has been made of them till within the last thirty or forty years. Indeed, in respect to many, one-half or one-third of that period would more correctly state the length of time they have been in use. A parallel to this fact is found in tanning materials; for Davy, in his lectures before the Agricultural Society of his time (1804—1812), seems to indicate that scarcely any material but oak bark was in use then. In fact, what Davy did for tanning, &c., Chêvreul has done for all manufactures, processes, &c., connected with oils and fats. Before the latter chemist discovered, in about 1820—'23, the nature of fats and fatty acids, we were quite unacquainted with the constituents of such substances ; and even long after he made the discovery it lay dormant. It was not, indeed, till the year 1831 that any really practical application was made of it ; and then the success was but partial.

Precisely the same observations may be made in regard to paraffin. It was first discovered by Reichenbach, in 1830 ; but, for twenty years afterwards, it remained so great a curiosity and rarity, that few of our most eminent chemists were acquainted with its properties, except by report ; and it was not till 1847 that Mr. Young first attempted to produce it on the large scale—an attempt not commercially successful for some years afterwards.

Now, in all these instances, although the existence of the stearine, tannin, or paraffin was well known, adequate means were wanting to put them into economic use. Further chemical knowledge was required to utilise the facts possessed. But as soon as this knowledge was available, each of these substances became a mine of wealth pecuniarily, and an enormous advantage socially. But their application had also a secondary use. As the manufacture of each became extended, so great a demand sprung up as to stimulate search for them in greater quantities. In respect to oils, fats, &c., this has resulted, in the course of a few years, in putting us into possession of about fifty new sources. In respect to tannin, which we have considered in the same parallel, at least thirty to forty new sources have arisen ; and paraffin, the youngest discovery of all, has similarly been obtained from largely extended sources, that, in total amount of production, eclipses the two previously named substances.

It thus happens, through every branch of applied science, that one discovery soon after leads to another, and thus—wave-like—goes on reproducing, until facts multiply so largely as to be scarcely capable of arrangement. The difficulty, however, is met in science, as in other matters, by sub-division of labour. One man adopts one branch, and others choose a different route of discovery. Separate mental energy is thus devoted to each subject ; and this is followed by great development, and consequent advantage and advancement to pure and applied science.

If the remarks thus made be true, and justly applicable to the matter already considered, they will be found still more so in connection with the practical uses of the substances that have been discovered. It will next be necessary that we should describe those processes by which the products already detailed are put into use. In doing this we may content ourselves with but a short notice of such matters in connection with lamp oils, and more fully devote attention to the manufacture of candles, &c. The remarks

already made in reference to the combustion of coal-gas, are equally adapted for the combustion of oils. But, of late years, a variety of new products have been introduced to replace oils altogether—such as naphtha, benzole, turpentine, various spirits, paraffin oil, petroleum, &c.; and to these we must also devote some space for consideration, but especially to the two latter, as they have so largely replaced oils of both the animal and vegetable kind.

In respect to lamp-forms, they are so numerous that we cannot enter into their description; more especially as the general principles of the best have been described, and because the old forms are constantly being replaced by new.

Manufacture of Candles from Stearine, Palmitine, Cocine, Spermaceti, Wax, Etc.

In the previous pages we have generally pointed out those processes by which the stearine or other solid matter of fats is extracted, and the oleine removed, so as to give the solid portions a higher temperature of liquefaction than that they have in combination with oleine. We now pass on to briefly notice certain mechanical and chemical details involved in the processes of candle-making; commencing with the lowest, and afterwards examining each improved form of candle.

Confining our attention to modern forms of candles, we first notice the humble rushlight, which, with little doubt, may be considered as the primitive form of its class. Rushes abound in most fenny districts; but the "trade" has always given the preference for those obtained in Lancashire. They grow in knotty masses, especially in places abounding, at certain seasons, with water. After cutting, they are dried, and then a strip of the external skin is taken off on either side, by persons called rush-peelers. At one time this formed a considerable means of occupation to poor women in London, who earned from six to ten shillings a week; but owing to the introduction of so many forms of night-lights, their occupation is gone.

The rushes, peeled, are used in much the same manner as ordinary candle-wick; that is, they are repeatedly dipped into melted tallow near the point of solidification, being cooled before each dipping, until they become sufficiently coated. All candles are sold according to the number of them required to make one pound, avoirdupois, in weight. Rushlights vary upwards from ten to the pound. Their light is very feeble; and, except for use as watch-lights, they are all but valueless as a means of artificial illumination.

The common dip-candle is of too well-known a character to require description. The emblem of incompletion and wastefulness in any and all branches of artificial illumination; equally so in the house, in respect to its spreading grease and sparks, to the despoliation of garments, and destruction of life and property; filthy smelling when not burning, and worse when in that condition;—we say, despite all the maledictions we can heap upon it, still, as a household commodity, it seems to defy extermination: despite the inventions of Palmer, Price, Wilson, Young, and others, it still keeps its place, as if defiant, notwithstanding its objectionable qualities, of all attempts to replace it. How to account for such a persistency of existence we know not: it must be accepted as an undoubted fact; for, from the mine to the cottage, the cottage to the villa, and the cognates of these to the king's palace, the immortal dip is still to be found as a source of light.

At p. 568, *ante*, we have given an exposition of all those principles involved in the construction and action of either lamp or candle-wick. We may therefore now only draw attention to the practical part of the subject. The cotton itself is generally best for the purpose as obtained from India (especially Madras or Surat); but the best kind for candle-wick purposes is that obtained from some parts of Asia Minor, and generally known as *Smyrna* in the trade. Candle-wicks made of other kinds of cotton, above-named, are technically known as *Wiltshire* and *Oxford*. The size of each thread varies from 6s to 7s mule-twist of the cotton trade; but it is so spun as to be more porous than ordinary cotton yarn—a matter easily managed in the practical operation of spinning. A finer sort of *Smyrna* cotton, called *Turkey*, was employed to make the wick of mould candles.

The wick is made by first winding the cotton from the "cops," a term applied to the conical mass of cotton yarn as obtained from the spindle of the spinning-frame (mule). Two threads are run together to form a ball of about three inches diameter. But a more usual plan is to wind the threads into a cylindrical mass of eight, ten, twelve, or fourteen threads, which can then be at once used, by a simple mechanical contrivance, to form the wick of the candle. This consists of a machine represented below.

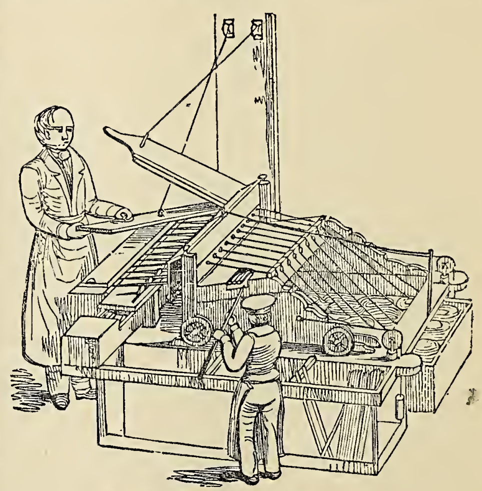


Fig. 441.—Candle-wick Machine.

On the right of the cut, a box will be noticed, containing the cylindrical balls, just named.

The strands from this are carried forward through eyes in a frame, and pass onwards to the cutter. By an ingenious contrivance, that cannot well be represented, the strand is first doubled, then slightly twisted, and afterwards cut so that any number of wicks, depending on the size of the machine, may be produced at one operation.

The wicks so produced are run on to a rod, like a yard stick, so that the looped end shall rest thereon, whilst the cut end shall hang down; the length of the wick, of course, determines that of the candle, the upper extremity of which is formed by the looped end of the wick, as may be easily noticed by inspecting a common dip.

Numbers of these rods, on which the wicks are hung at a distance of two or three inches from each other, are then placed horizontally in a frame, so that the wicks hang perpendicularly. The frame with these rods is suspended over a trough containing melted tallow, nearly on the point of setting; and, by means of a counterpoise, they can be either kept over the trough, or lowered by the hand into the tallow. On this latter being done each wick becomes coated with tallow, when the frame is raised, and the tallow allowed to solidify in the open air. Coat after coat is successively put on to the wick, until the candle has become of the size desired, whether as regards length or thickness. A form of the candle machine is represented in the

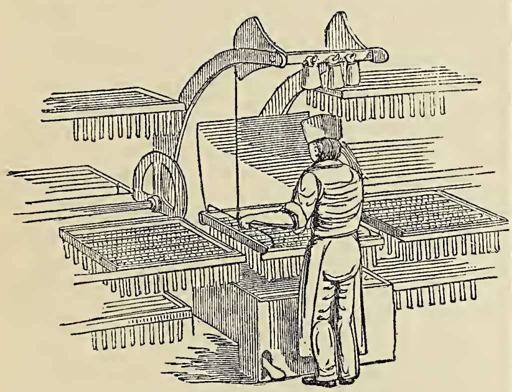


Fig. 442.—Dip-candle Machine.

above cut, and it will sufficiently explain itself in connection with the preceding description.

The chemical defects of a dip-candle are manifested by its external appearance. In the first place, it is of irregular thickness throughout, owing, in a great measure, to the shape of the internal wick. Next, the wick itself is irregular in size, whether in respect to each thread or its entire mass. Lastly, as already pointed out, the tallow itself is of so heterogeneous a chemical composition, as to render regularity of burning perfectly out of the question. As previously mentioned, a dip varies from 120 to 190 grains per hour of tallow consumption; and, with the best snuffing, does not give a light equal to one-third of that of a standard 120 grain per hour sperm candle.

Some of its defects, however, are corrected or lessened in the mould candle. In this the wick is made of superior material, and finer spinning than that of the dip. Instead of being coated by dipping, the mould wick is fixed in a tin mould, ending in a conical head, through which the lighting end of the wick passes externally, whilst that end that appears at the lower part of the candle is held by a wire at the open and wide end of the mould. Any number of these are arranged in a frame, with the wide end of the mould, and consequently of the candle, uppermost; the moulds, of course, are placed vertically. The frame forms a trough, into which the melted tallow is poured; and it runs into the moulds, and fills them. When the fat is solidified each candle is removed; and, owing to the internal polished surface of the tin, its external surface is also polished. All the best forms of composite, stearine, paraffin, sperm, and margarine candles are produced in a similar manner.

The defects of the mould, however, are but little less than those of the dip. It is certainly more sightly, and neater in appearance; but still all the faults of requiring snuffing, its guttering, emission of sparks, &c., made it a desideratum to find a candle not only free from such objections, but also possessing qualities of a different and superior nature in all respects.

Having had much to do with the earliest attempts to discover something better than the mould, and less expensive than the wax candle, which was about four times its price, we do not hesitate to relate some of the difficulties, resulting at last in success, that originally had to be combated with; remarking, that at the period we now refer to—forty years ago—Chévreul's discoveries, already repeatedly referred to, had not in the least degree, in this country, made any way in the candle trade.

It was first attempted to make the tallow of the mould harder; for even the unscientific tallow-chandler had discovered that the higher the temperature at which the tallow melted, the better was the light, and the more durable the candle. Best moulds were, therefore, made of the kidney and other firm fat of animals; and still further to harden it, alum was much used, which also imparted an increased whiteness to the tallow.

But the difficulty still lay in attempting to make the candle self-snuffing. So much was this desired, and so important was the result considered, that we were offered an almost fabulous sum, considering the apparently trifling nature of the object, for a successful result. A partial success at the period now referred to, as applied to common dips, had an amusing result. We forwarded, as an experiment, to a large tallow-chandler some wicks for tallow dips, that would snuff themselves; and on the second night of the sale of candles made with them, the rush of customers was so great as to necessitate the aid of the police to moderate the ardour of purchasers of the lower classes, anxious to obtain a cheap and efficient means of light.

But the attempt, from certain mechanical

difficulties, failed. There was no inherent difficulty, in any way, in respect to the processes we had proposed; but they were not in accordance with the pre-established system of candle manufacture; and, on the large commercial scale, it was not until the firm of Palmer & Co., and that of Price & Co., adopted Chévreul's discoveries, in part or wholly, and commenced the manufacture of self-snuffing candles on scientific principles, that any progress was made in affording a really efficient and generally useful candle to the consumer.

When Palmer & Co. first produced their yellow palm double-wicked dip, that gave a light somewhat resembling, but smaller, than the bat's-wing gas-burner, the eagerness of purchasers at their works was amusing and astonishing. In fact, the demand for them was simply enormous. The material consisted of unbleached palm oil, mixed, we believe, with tallow, or tallow stearine. The wick, made of cotton, was twisted tight, like a piece of whipcord, and double, so that, as the candle burned, each part of the wick spread out of the flame, forming the shape of flame just described; and, being coated internally with a metallic composition (bismuth, we believe), rapidly consumed itself away. It hence became self-snuffing; gave a brilliant light; and, despite all its defects, was an admirable addition to our means of producing artificial light for house purposes.

It was, however, an expensive and wasteful method. Speaking from memory, the candles burnt in a stick, like the ordinary dip, lasted but two and a-half to three hours. They could not be safely moved about, because then the fat rapidly melted, and caused guttering. The smell, again, was very offensive to some persons, although agreeable to others. Altogether, great as was the improvement thus effected, it left much to be sought for. We omit notice of the candle-lamp, with double or more wicks, made by the same firm, because, practically, it was simply a modification of the tallow mould, quite unfit to be burnt in a candlestick.

We have already noticed, frequently, that in making self-snuffing candles, both the wick and the fuel presented difficulties; and in Palmer's candles these had, to a certain extent, been overcome. But this was done at a considerable cost by the waste of the fat, the double wick consuming it rapidly, especially in the impure condition that it was then used.

The earliest improvements arose from the discovery and use of stearine as obtained from tallow, and for which Chévreul and Gay-Lussac took out patents about the year 1825. But still the difficulty occurred in the wick; and it was not until Cambacères invented the plaited wick, with which our readers are now so familiar, that such candles as at present of common use became the least in vogue. But the plaited wick presented many difficulties in its manufacture and use. At the time it was first brought out, we vainly endeavoured to induce all the leading owners of plaiting machines to make even a few yards of wick for experimental purposes; but, supposing that could have been done with the then constituted machines, other difficulties occurred in respect to the burning properties of the cotton. The leading candle-makers used what is known in the cotton-yarn trade as yarn, called 30s to 36s, in its bleached state; but this was so charged with mineral impurities that it would not burn, or rather bend out to burn from the flame, frequently standing as upright as the wick of the common mould or dip.

Various methods were tried to induce the wick to behave better. It was soaked with carbonate of soda, borax, and numerous mineral salts, which—one or other of them—at last removed the difficulty. But another arose in the crystallising tendency of the stearine. We have seen, frequently, the composite candles of the time to which we are referring, completely hollow, although externally, to all appearances, perfect. To remedy this, many methods were proposed, and amongst them the introduction of arsenic—the white arsenic of the shops. On one occasion we saw this plentifully supplied from a "pepper-box," the powder being thus cast into the melted stearine. But, unfortunately for the makers, this objectionable and dangerous plan got bruited abroad, and sudden, but by no means unjust, fright caused a strong prejudice against the new candles. Public feeling rose so strong that the sale of the candles became barely possible. Eventually, science stepped in to the rescue; and the heating of the moulds, and pouring the fat into them at a temperature not far short of its solidifying point, cured the evil.

A question of price became another hindrance to the sale of the candles, as they were charged from 30 to 50 per cent. higher than the best moulds. This necessarily arose from the expensive manner in which the stearine was separated from the oleine; independently of which, the secondary product, glycerine (so much used at the present day, and a source of considerable profit), was wasted.

Chévreul's method was that of saponification. The stearic and other acids were converted into soap by the action of potash and soda, and then decomposed by sulphuric acid. By subsequent pressure, &c., the stearine was thus separated in an available form. In 1831, however, De Milly, of Paris, adopted the use of lime, which, being an earth having alkaline properties, could be substituted for the more expensive articles, potash and soda. By his process, the materials—tallow, palm oil, &c.—are melted together in a vessel by means of steam; and when all are liquefied, slaked lime is introduced. The steam is still supplied to give heat to, and agitation in, the fluid for some hours, until a complete soap-form of the fatty acids and lime is afforded. The impurities being allowed to settle, and the soap to solidify on the surface, the solid material is removed and powdered. Afterwards mixed with water, it is raised to a boiling temperature by steam, and dilute sulphuric acid is added. The acid combines with the lime, forming the sulphate of the earth; whilst the fatty acids, having a weaker affinity, are set free. The liquid being then allowed to cool, affords solid

masses, containing oleine, stearine, margarine, palmitine, cocine, &c., according to the materials that were first employed. By pressure in a hydraulic press the oleine is removed, and with it the greater portion of the colouring matter. By further treatment with dilute sulphuric acid, as already mentioned at p. 637, as being adopted for purifying oils, after re-melting and cooling, a purer mass is obtained, that is exposed to pressure; and at last the solid substance is afforded, of a pure white colour, and hard, resembling vegetable ivory.

Subsequently more simple and direct processes were invented; the materials being all melted, and heated to a temperature of 350°; and a seventeenth part of their weight of sulphuric acid is added, by which the fatty matters are converted into a black-looking mass. This is withdrawn in a melted state, and boiled with water by steam. It is then conveyed to a still, and exposed to a heat of 560°, by superheated steam, and thus the stearic and other fatty acids become converted into vapour, and are distilled over. The substance obtained contains the various acids (oleic, stearic, palmitic, &c.) that the material can afford, and the oleic is separated by the same method as that just described, and purification is similarly conducted, leaving the stearine, palmitine, &c., in a pure, white, ivory-like condition.

Another method was that of forming double acids by the action of sulphuric acid on the fat, whereby the sulpho-stearic, sulpho-margaric, &c., were produced. The compound is readily decomposable by the addition of boiling water, to which the sulphuric acid attaches itself, leaving the fatty acids free.

Numerous other plans, new, or modifications of the preceding, have been proposed, and adopted with a greater or less amount of success. But their multiplicity in number and detail forbids our entering into their description. Sufficient has been said in our pages to put our readers in possession of all the leading facts of the process, and the minor particulars are too numerous for discussion in this work.

Several methods were at first attempted to bleach the coloured fats, especially the yellow kind, such as palm oil. For this purpose many highly oxidised compounds were used, as nitric or nitrous acid, bichromate of potass, &c.: but the removal of the oleine, if perfectly performed, is about the most sure method; for, being the only liquid portion, it necessarily contains the impurities either in solution or suspension; hence, if it be properly expressed, or otherwise removed, the whiteness of the solid portion must follow. Air and light have great bleaching powers; and hence a candle of a yellow colour, made of palm oil, will soon become bleached if freely exposed to the action of air and light, arising, without doubt, from some peculiar action in promoting chemical composition.

This description of the generally-used methods of obtaining stearine, palmitine, &c., is equally applicable in respect to all other animal fats, as from the various butters, &c., already detailed, with their sources, in our previous pages (see *ante*, p. 700, *et seq.*); and it will therefore be needless, for some minor details, to inquire further into the subject. The mode of making candles from all these materials, and others of a solid nature, that have to be described, is identical with that already given as adopted in making mould tallow candles.

At p. 642, *ante*, we have already stated the source of sperm oil, as a fatty substance obtained from various species of the Cachalot, the *Physeter macrocephalus*, &c. Although, like the stearine of the oils that have been already described, and mixed, therefore, with other fatty fluids of the entire body of such whales, it is chiefly obtained from the head, in its front, over the nostrils. The method of separating the spermaceti is that of first heating and straining the mass. By subsequent cooling to a temperature not higher than 50°, the spermaceti becomes a brown semi-solid mass, and it is separated from the oil by pressure in bags, as already mentioned in this page, when the separation of stearine from tallow, by pressure, was described. The coarse material is then heated by steam, cooled, and afterwards submitted to great pressure. By subsequent melting with caustic soda, and boiling, the whole of the remaining oily matter is removed in the form of a soap. The spermaceti floating on the surface of the water is then cooled, reduced to powder, pressed repeatedly, and again cooled; it is again treated with an alkali; and, at last, obtained in blocks, the inner surface of which shows a beautiful crystalline structure. This is called *cetine*, and it is the analogue of stearine, palmitine, &c. Like them, it is an acid, the cetylic, united with an alcohol called *ethal*. The candles made from spermaceti are remarkably even in their rate of combustion; and, for this reason, have been chosen as the standard in all photometrical trials of gas, and other illuminating agents dependent on the combustion of hydrocarbons generally.

Margarine has been repeatedly noticed before in connection with stearine, from which it has been at times separated, to make candles of a beautiful pearly lustre. Glycerine, that has also been frequently mentioned, is a sweet liquid, produced during the decomposition of fats. It is of great value for medicinal and pharmaceutical purposes; and from being a waste product of no value, it has become one of high importance. It is now largely introduced into soaps, because of its peculiar preventive, or rather protective, action on the skin in respect to chafing by air, hard water, and other causes.

It has been frequently noticed that one discovery of importance is generally followed, consequently, by another having a relation to it either in principle or fact; and this holds singularly true in regard to glycerine.

About twenty years ago, the discovery of guncotton caused much interest to the scientific world, and in military circles, as it seemed very likely to supersede gunpowder for a variety of purposes. Although experience has not tended to prove this, still there are purposes—as, for example, blasting rocks, &c.—in which gun-

cotton may be advantageously used. It is prepared by the action of strong sulphuric and nitric acids on carded cotton wool, when the substance, although apparently quite unaltered in external physical appearance, is chemically changed, and taking up nitrogen, it becomes highly explosive by heat.

Glycerine can be similarly acted on ; and, in 1847, M. Sobrero discovered that, if it be treated with a mixture of sulphuric and nitric acids, it yields an oily liquid, heavier, and almost insoluble in water, but readily soluble in alcohol and ether. This liquid is now generally known as *Nitroglycerine*, or *Glonoine*. It has been largely prepared as a substitute for gunpowder in blasting; but is exceedingly dangerous, unless carefully dealt with. Some serious accidents to life and property have been caused by it.

A considerable interest is attached to this substance; and as it is a product connected, through glycerine, with the processes we have described, the following account of its preparation, by Mr. Redwood, will doubtless be acceptable to many of our readers. He remarks—

"After repeated experiments, I found the following [to be] the best mode of preparation :—100 grammes (1543·3 grains) of glycerine, freed as much as possible from water, and having a specific gravity of 1·262, were cautiously, and in small quantities at a time, added to 200 cubic centimetres (about eighteen ounces) of monohydrated nitric acid, previously immersed in a freezing mixture. The temperature rises on each addition. It is, therefore, necessary to allow the mixture to cool down again to — 10° C., or 14° Fah., before any fresh addition is made, as it is very necessary that the temperature should never rise above 0° C. ; that is, 32° Fah. When the glycerine and nitric acid have formed a homogeneous fluid, which may be facilitated by stirring the mixture with a glass rod, 200 cubic centimetres (or eighteen ounces) of concentrated sulphuric acid are to be cautiously and slowly added.

"This operation is accompanied with the greatest danger* if the temperature is not continually watched. Experience, however, shows me that there is no reason for fear, provided the temperature be always kept below 0° C., or 32° Fah.

"Once I saw a temperature run up to 10° C., or 50° Fah., without causing any explosion ; but between 10° C. and 20° C. a violent reaction suddenly takes place, and the mixture is violently propelled from the vessel. I, however, repeat, that such an accident can be safely avoided by keeping the temperature below 0° C. [or freezing point of Fahrenheit].

"When these precautions have been taken the nitroglycerine separates, after the addition of sulphuric acid, in the form of an oily liquid floating on the surface, and may be collected by means of a separating funnel.

"The products thus obtained are then dissolved in a small quantity of ether, and the solution is to be repeatedly shaken with water, until all trace of acid is removed. The ethereal solution is then heated over a water-bath till nothing more is volatilised. The resulting quantity will be about 184 grammes (or 2836·6 grains). The composition of glycerine being $C_6\ H_8\ O_6 = 92$, and 100 parts of glycerine yielding 184 of nitroglycerine, we may infer that the composition of nitroglycerine is $C_6\ H_2\ NO_4\ O_6 = 132$. I am, at present, endeavouring to ascertain if this inference is correct.

"It is difficult to determine accurately the point at which explosion takes place ; it is best observed by allowing the nitroglycerine to drop, from time to time, upon a piece of heated porcelain. At first it burns away with a vivid flame ; but as the temperature diminishes it violently explodes, evolving red vapours, and frequently breaking the porcelain on which it falls.

"By placing a drop on an anvil, and striking it with a hammer, it instantly detonates. When properly prepared, and free from acid, it may be kept for any length of time. I have some in my possession which has been kept for two years without undergoing the slightest change.

"Upon the addition of sulphuric acid to the ethereal solution, decomposition ensues, and a great quantity of sulphur is thrown down." The at present received composition of nitroglycerine is that of a nitrate of the oxide of glycyl, the latter substance being analogous to ethyl, methyl, amyl, &c., &c.

Last of the solid substances used in candle-making, we may name the various kinds of wax. That of the bee is simply the result of mechanical collection by the insect, and not of secretion, as some have supposed. It is procured from the honeycomb, of which it, indeed, forms the cells ; and when melted and cooled, it affords the well-known yellow beeswax of commerce. The bleaching of this is effected by first reducing it to a liquid state by heat, in water containing a dilute solution of sulphuric acid. The whole is kept in constant movement, so that the acid may equally act on all parts. The mixture, on being allowed to rest, deposits the impurities, and the wax remains floating at the top as a slightly-yellow fluid. It is then converted into exceedingly thin films, by allowing it to pass through fine tubes, on to a drum revolving in cold water, when it assumes the shape of long thin ribbons. These are exposed to air, light, and moisture, by which means the wax generally becomes whitened ; the melting and conversion into ribbons being repeated during the process, so that fresh surfaces of wax may be exposed to the bleaching action of the air. It is then melted, and cast into thin cakes.

The sources of vegetable wax are numerous. Japan wax is obtained from the *Rhus succedanea*, order *Anacardiaceæ*. It is afforded by the fruit of the tree, and is now largely imported for candle-making. Insect wax is deposited by a species of *Coccus*, the *C. pela*, on the leaves of a species of ash, the Chinese kind, or *Fraxinus sinensis*. Palm wax is chiefly obtained from

* Mr. Redwood lost the use of his eyesight for a considerable time, owing to an explosion that occurred during his early experiments.

some of the *Ceroxylon*, order *Palmaceæ*, being produced on the surface of the young leaves of the plant by the *Copernicia cerifera*, and scraped off the trunk of the *Ceroxylon andicola*, each of these trees yielding about twenty-five pounds weight. This wax is used with the stearine of tallow for candle-making. Species of *Myrica*, as the candleberry, afford berries that produce wax when exposed to heat. But generally, wax is an exceedingly abundant production of plants, especially of the leaves, flowers, and fruits; but it is only in certain cases that it is produced in sufficient abundance to be worth collecting for commercial purposes.

Wax candles are generally composed of a mixture of wax and stearine. They are not made in moulds, like all the preceding, but by a process of dipping, to place the wax on the surface of the wick. By rolling on a warm plate the candle is afforded of a cylindrical shape, and polished surface. Formerly, wax was largely used for the best kind of candles; but the discoveries, and their applications, detailed in the preceding pages, have almost entirely replaced it—at all events, in these islands.

Liquid Illuminating Products of Wood, Coal, Etc.

Last in our examination of substances that can be used as illuminating agents, are those liquids obtained by the dry distillation of vegetable and mineral matter, with which we shall also include paraffin, both as an oil, and as a solid for making candles.

Alcohol, or spirits of wine, is far too expensive in this country to be employed for illuminating purposes, owing to the heavy duty on it for fiscal reasons. In the absence of this it could be produced and sold cheap enough. But by itself it would be useless, owing to the little light given during its combustion. Abroad, however, and mixed with turpentine, it has been employed. In France, this mixture goes by the name of *Eclairage au Gaz Liquide*, and is burnt in a lamp expressly constructed for that purpose. The liquid may be made of any relative proportions of the two constituents, so as to afford a good light. It consists generally of about equal parts of alcohol and turpentine, not by mere mixture, but by distilling the two liquids together, when one having a specific gravity of 823, and a boiling-point at 190°, is afforded. The vapour being highly explosive if mixed with air, renders the lamp dangerous in use.

Benzole, formerly a dear product, is now produced in great quantities by distillation of coal-tar, and, as already noticed at p. 600, *ante*, is now largely used as a source of nitrobenzole and aniline. We have also, at p. 603, *ante*, named its use for naphthalising gas.

It is a limpid liquid, having rather an agreeable odour, boiling at 180°, and with a specific gravity of about 850. As an addition to alcohol it affords the necessary amount of carbon to give a bright white light, and may be used instead of turpentine in the lamp just described. It is extremely volatile in relation to gases; and hence, if pure hydrogen be passed through it, the gas will burn with a brilliant flame. Even atmospheric air may be so "naphthalised" by it as to burn like coal-gas. This has already been noticed at the page just referred to.

Coal-naphtha is a product of tar, much used in the common street lamps, that, burning without a wick, and being cheap and abundantly produced, is an important illuminating liquid. The lamp represented in the margin is that usually employed. *a* is the reservoir in which the naphtha is stored; and its supply to the burner, *c*, is regulated by a stopcock, fixed in *b*, the tube by which the spirit reaches the burner. To obtain coal-naphtha, the tar is distilled, by which crude naphtha, with other products, are drawn over and condensed. By a second distillation, the naphtha is obtained in a fit form for burning. It has a strong odour, partly of coal-gas and tar; a specific gravity ranging nearly to 900; and is soluble in alcohol, wood-naphtha, &c. By mixture with sulphuric acid, washing and re-distillation, this coarse product may be converted into one fit for burning with a wick.

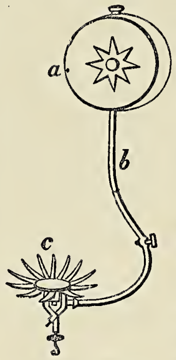


Fig. 443.

Wood-naphtha, obtained by the distillation of wood, is too much like alcohol, in its properties and burning, to be of any value as an illuminating agent; but, like the latter, it may be used with turpentine and benzole. Formerly, all the spirits that have been named were much used; but, within the last few years, the abundant supply of petroleum and paraffin has greatly diminished their use—at all events in this country. The oil obtained during the rectification of corn spirit, and known as oil of grain, or fusel oil, has also become similarly disused; for it is now largely employed in making artificial essences used in confectionery—a singular but beautiful application of chemical science, that enables us, from this oil, rotten cheese, and rancid butter, to obtain such flavours as pineapple, pear, jargonelle pear, apple, strawberry, &c., and to substitute such essences for the fruit.

Petroleum has long been known as an illuminating agent; and was limitedly employed in some parts of Sicily, for that purpose, centuries ago. Until recently its sources were comparatively few, and its use extremely small. The Isle of Trinidad, Rangoon, Cape de Verde Islands, and a few other places, were its only sources. The discovery of oil wells in the United States has, of recent years, caused its use to become enormously increased. In many parts it is there found literally in wells, and, at times, almost as a river: and the quantity that is now afforded by mere pumping, far exceeds the wants of civilisation. It has, indeed, become one of the most remarkable and abundant of all mineral products.

As first obtained it is utterly unfit for burning in lamps, containing, as it does, a large amount of spirit that is inflammable at a low temperature, and exceedingly liable to produce explosions, the cause and prevention of which will presently be more fully noticed. It requires rectification, which is conducted in a similar manner to that of paraffin.

This latter product has, perhaps, revolutionised the trade in oils and fats, to an extent that has a parallel only in the adaptation of coal-tar colours in the art of dyeing and calico-printing. As previously noticed, it was discovered by Reichenbach about the year 1830, but was not brought into actual use till about the year 1855; and some little time after that passed before it became of general use as an illuminating oil. All rich hydrocarbonous coals produce it on distillation at a little below red heat; but its source in this country is the Boghead coal, obtained between Bathgate and Airdrie, in Scotland. Mr. Young first established his works near the former town; and, at that time, it was believed that the coal could only be found in that neighbourhood. But, as previously stated, when considering this material as a source of coal-gas, the area of its distribution has of late years been found to be as above given, and with every probability that it may eventually extend much further.

The mineral has a dull black appearance, not unlike anthracite; but its chemical constitution is the reverse of that material, for it abounds in hydrocarbons, whilst anthracite is almost entirely composed of carbon, with a trifling per-centage of hydrogen. According to Mr. Young's process, the coal is cast into vertical retorts, which are exposed to a heat a little below redness. The products of distillation are condensed, and conveyed to a reservoir, a highly inflammable gas being allowed to pass off; this is generally burnt outside of the works: hence these usually present the singular appearance of a large white flame issuing from a pipe on the roof.

The crude oil thus obtained is first distilled, and condensed at as low a temperature as possible. The rectified oil so afforded is next purified by agitating it with sulphuric acid. It is then drawn off, and mixed with a solution of caustic soda in water. Both of these processes are repeated, together with distillation; and thus the naphtha, or dangerous spirit, is removed. The process is completed by a final distillation, and the oil becomes an excellent lubricating agent, as well as one of our best sources of artificial light.

Solid paraffin is a product of this oil, obtained by cold and pressure, in a very similar manner to that already described for producing stearine from oils, &c. It is the material now so extensively produced for the purpose of making the so-called—and very justly—" gas candles."

At first great prejudice existed against the use of paraffin in lamps, owing to the occurrence of several explosions, that not only caused loss of life, but extensive fires—a circumstance that has also frequently occurred in the use of petroleum. But, in all such cases, the cause of the explosion could be directly traced to the impurity of the liquid used; that is, the oil had not been properly rectified. Mr. Young, with a most praiseworthy perseverance, had every inquiry or inquest attended by a legal gentleman, who, through careful cross-examination, established this fact; and it has been satisfactorily shown, that an explosion had never occurred if his paraffin oil had been employed as sent out from his works.

We are indebted to the Manager of Young's Paraffin Light and Mineral Oil Company, Limited, for the following description of their works as existing in 1881, and the operations carried on there. Some historical notices, at which we have only briefly glanced, are also afforded. The works described are situated at Addiewell, West Calder, a village in Scotland situated between Edinburgh and Glasgow.

The word "paraffin" is almost new to our language. It was first applied to a white substance obtained by Dr. Reichenbach from the distillation of wood, but was not heard of outside treatises on chemistry until the year 1847, when it was applied by Mr. James Young to a natural oil which he obtained in Derbyshire, England.

In that year Mr. Lyon Playfair called his attention to a stream of thick dark oily fluid which trickled from the sandstone roof of an old coal-mine. The peculiarity of the liquid arrested his attention, and after due consideration he arrived at the conclusion that this substance, which was, through ignorance, allowed to run to waste, contained properties of a very remarkable and valuable character. He immediately began a series of experiments, bringing to the prosecution of this work great experience and knowledge as a practical chemist. The result far exceeded his expectations. Subjected to distillation, the coarse dark fluid yielded a pale, yellow-coloured oil, in which, as the liquid cooled down, crystals of paraffin wax formed. This discovery led to the establishment in Derbyshire of a small manufactory for the distilling of burning and lubricating oils from the crude petroleum issuing from the coal-mine, which for two years proved exceedingly remunerative.

Suddenly the supply of the raw material ceased, the stream of natural oil having dried up. But fortunately Mr. Young's thoughts had been turned to the causes which had produced this petroleum stream, and he came to the conclusion that it was the result of the slow distillation of coal by subterranean heat. The theory of the origin of petroleum thus formed by Mr. Young still continues to be the only satisfactory one to account for the vast stores of natural oils which have now been found in such enormous quantities in America, Europe, and Asia.

With that theory to guide him, Mr. Young experimented upon coal, and found that, when subjected to distillation at a low temperature, it yielded an oil similar in character to the petroleum, or natural oil, which he had found in Derbyshire.

The next step in order to secure success was

to obtain a coal that would give the largest possible percentage of crude oil. After a long search Mr. Young was rewarded by finding such a mineral in Linlithgowshire, near the town of Bathgate, and lost no time in securing a supply from this coalfield. Works were soon after erected, which in the course of a few years converted a small weaving town into a populous and industrious hive of upwards of six thousand inhabitants.

This mineral has since become famous under the well-known name of Boghead coal. In the course of a few years, however, it became exhausted; but before that point was reached, experiments had been made with a mineral, now well known under the name of shale, which hitherto had been considered of no value. It was found that this mineral, at the low prices at which it could be obtained, yielded a sufficient quantity of oil to make its distillation remunerative.

Since the year 1866 all the paraffin oil manufactured in Scotland has been distilled from shale, no field equal to that of the Boghead mineral having since been discovered.

Leaving the history of our subject, we shall glance next at the various processes of its manufacture, and here the most wonderful part of the tale has to be related. Few persons who are accustomed to see the pure white candles, more transparent than wax, and the colourless oil, clear as water, have any idea that both are obtained from a dull, dark, compact mineral, totally devoid of the lustre which gives to coal the appellation of the "black diamond." And yet this seeming miracle is achieved by the aid of chemistry. The process by which the change is effected is complicated and laborious, but, freed from its technicalities, it may be easily explained as follows :—

The first operation after the shale is brought from the pits is to pass it through powerful crushing machines, which break it up into small pieces. It is then conveyed to the retorts, in which, under the influence of heat, the coal is decomposed, its oil being driven off in the form of vapour, which is collected in a large main pipe having a connection with all the retorts. This main pipe conveys the oil vapour to condensers, in which it becomes reduced to a liquid form. At this stage the oil has a black, greasy appearance. It is now subjected to a variety of operations for the purpose of being refined and separated into various marketable products. It would take up too much space to detail these operations minutely. They consist, however, of repeated distillations and treatments with sulphuric acid and caustic soda, by which means all impurities are removed from the oil.

The first valuable product that is obtained from the distillation of shale is—

Sulphate of Ammonia.—A ton of shale, according to quality, yields from ten to twenty pounds' weight of that chemical. Although this quantity appears small, yet, in the aggregate, the quantity of shale distilled is so enormous that many thousand tons of sulphate of ammonia are annually produced by the paraffin oil works of Scotland. It is a most valuable agent for manurial purposes, and is largely used by farmers at home, and also by sugar growers, wherever beetroot or the sugar-cane is cultivated on the Continent, in the East and West Indies, and in America.

The next product that comes off is—

Naphtha.—This is the lightest portion of the crude oil, and is a very valuable product, being largely used in many manufacturing operations. Young's Company, by a patent process of their own, obtain two qualities. The lighter, which is termed "Gasoline," is used for making air-gas under the various patents which have been recently brought out for that purpose. The heavier portion of the naphtha is used as a solvent in indiarubber and other similar factories, and is also used as a substitute for turpentine in the manufacture of paints.

It is of the utmost importance that this spirit should be carefully removed from the—

Burning Oil—which is the next product obtained. This is the great distinguishing feature between most of the home-made oils and the petroleums which come from America. In America no sufficient market exists for all the naphtha that is produced. The temptation, therefore, is very strong to leave as much of it as possible in the burning oil, which is thus rendered more or less dangerous, and has given rise to accidents and fires so numerous and so destructive to life and property, that nearly every country has been compelled to use some means of testing these oils in order to secure some degree of safety. The various tests, however, which have been adopted are, to a very large extent, evaded, and dangerous petroleums still find their way into the various markets of the world.

Young's Company have always adhered to a standard of safety, which makes accidents from this cause quite impossible, and it must be a satisfaction to themselves, as well as a guarantee to the public, that ever since Young's oil was introduced in 1847, not a single accident has ever arisen in any part of the world from its use.

The residue which remains after the burning oil has been distilled off is a mixture of heavy oil and solid paraffin. The paraffin is separated from the oil by a process of filtration under pressure, and the heavy liquid is then purified by distillation and chemical treatment, and made into—

Lubricating Oil of a beautiful pale yellow colour. It is sold either in the pure state or mixed with various animal and vegetable oils, suitable for every description of machinery These oils retain their sweetness for a long period, and are not liable to become viscid. They entirely prevent gumming on the bearings of machinery. Further, an almost invaluable characteristic of this mineral lubricating oil is that, when cotton or other waste is saturated with it, it has no tendency whatever to spontaneous ignition, and when mixed with any other fatty oil, entirely prevents fires arising from this source, to which all animal and vegetable oils are more or less liable.

Young's Company sell very large quantities of these oils in all the manufacturing districts of Great Britain. They are used extensively in cotton and woollen factories, engineering shops, and by railway companies. A good trade has also been developed on the continent through the various branches and agencies which the Company have established, and their exports to India are yearly increasing, where these oils are used for batching purposes in the numerous jute factories which have been erected in the East.

The next product—

Paraffin Wax, which is taken from the heavy oil, may be said to be one of the most curious and valuable of the products of the distillation of bituminous shale. In the crude state it is of a dark brown colour, but when refined and freed from its oily and tarry impurities, it becomes a beautiful white, alabaster-like material, free from smell and taste. This wax is used for a great variety of purposes; by brewers, for coating the inside of their beer casks; by spinners and weavers in the manufacture of their yarn and cloth. It has also been found of much service by the surgeon in dressing wounds. The great outlet, however, for disposing of this material is in the manufacture of matches, and for making—

Candles.—Young's Company have a very extensive candle factory, from which they turn out candles of almost every description and variety, and suitable for burning in all climates. Paraffin candles are more economical than any other description of candle, as while they give a better light, they also burn much longer than tallow or stearine candles. For instance, one pound of stearine candles will only burn for 46 hours, whereas the same weight of paraffin candles will burn for 58 hours.

The manufacture of the paraffin into candles is, perhaps, one of the most interesting sights at the Addiewell establishment. The cakes of paraffin are taken to the candle-house, where they are put into large tubs and melted by the application of steam. When melted the paraffin is drawn off into small vats and carried to the candle-makers. The candle machines stand in rows along the room. On the top of the machine is a wooden clamp holding a double row of candles already cast. About two inches below are the candle moulds sunk in a small trough, and at the bottom of them is a tube, the upper part of which forms the head of the candle, and through which the wicks are run off rolls. These tubes at the bottom and the row of candles at the top keep the wick in position in the centre of the hole, the wicks not being cut until the paraffin has sufficiently cooled to keep them in their proper place. The moulds having been heated by a current of steam passing through the troughs, the hot liquid paraffin is poured in. The steam is then turned off, and cold water takes the place of the hot water, which rapidly solidifies the paraffin, after which the wick is cut. The rows of candles in the clamp or holder are dressed and removed, and the candles in the mould take their place, leaving the moulds ready to be filled again.

When Mr. Young first introduced paraffin oil for burning he was met with the difficulty that no suitable lamp existed in which it could be burned. This difficulty he at once grappled with and overcame. A manufactory was established at Lochrin, Edinburgh, which was the first of its kind. Since then the manufacture of paraffin lamps has increased enormously, not only in this country, but on the Continent of Europe and in the United States of America.

During the present year (1880) the Company erected a large building in Birmingham. It is fitted up with every modern improvement and appliance.

The Company have always recognised the importance of supplying lamps strong and durable, of first-class workmanship, and of the best materials, their object being mainly to provide the public with lamps best adapted for the efficient and economical combustion of paraffin oil, so that there shall be no waste, and that the light given shall be the utmost that the oil is capable of yielding. The variety of their form, style, and cost is very great. They vary in price from 9d. up to £10 each. Among these we observe lamps suitable for the cottage table or wall, lanterns for the stable, for ships, or streets, and lamps embodying expensive material, combining artistic forms for use in the parlour, the dining and the drawing-room, pillar lamps for churches, chandelier lamps for lobbies, rooms, and ships' cabins, and bracket or mantel-piece lamps for bed-rooms and offices. Silver, bronze, iron, brass, china, marble, and glass are used in their construction, and the styles include statuary after classical and modern models, and architectural combinations and groupings from the vegetable world in endless variety.

Young's Company have been regular exhibitors at all the great international and colonial exhibitions, and the excellence of their products has secured for them gold medals or other highest awards at these Exhibitions.

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